Sampling and Analysis Plan

Lower Fox River Pre-Design Characterization Study
Lower Fox River, Wisconsin

Prepared for:

Wisconsin Department of Natural Resources

and

United States Environmental Protection Agency
Region V Superfund

Prepared by:

The RETEC Group, Inc.
MAKuehl Company
En Chem, Inc.
Natural Resource Technology, Inc.

November 2003

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List of Acronyms

±	plus or minus
AGC	Associated General Contractors of America
ANSI	American National Standards Institute
ARI	Analytical Resources, Inc.
ASCE	American Society of Civil Engineers and its associated Construction Institute
ASPRS	American Society for Photogrammetry and Remote Sensing
ASTM	American Society for Testing and Materials
BDL	below detection limit
BOD	biological oxygen demand
BODR	Basis of Design Report
CDF	Confined Disposal Facility
CH	highly plastic clay
cm	centimeter
COD	chemical oxygen demand
cy	cubic yard
DEA	Detailed Evaluation of Alternatives
DGPS	Differential Global Positioning System
DOC	dissolved organic carbon
DTM	digital terrain model
EDD	electronic data deliverable
EIMS	Environmental Information Management System
EPA	United States Environmental Protection Agency
FIELDS	Field Environmental Decision Support
FRDB	Fox River Database
FS	Feasibility Study
GAC	granular-activated carbon
GC-ECD	gas chromatography with electron capture detector
GIS	Geographic Information System
GPS	Global Positioning System
HIPA	United States Department of Transportation Federal Highway Administration Office of Program Administration
IA kit	Hybrizyme PCB immunoassay kit
kg	Kilograms
kHz	Kilohertz
LFRPD	Lower Fox River Pre-Design Sediment Characterization Study
LOD	limit of detection
LOQ	limit of quantification
LTMP	Long-term Monitoring Plan
MDL	method detection limit
mg/kg	milligram per kilogram
MH	high-compressibility silt
mi^2	square mile
MNR	monitored natural recovery
MSCL	multi-sensor core logger

List of Acronyms

NAVD	North American Vertical Datum
NGS	National Geodetic Survey
NOAA	National Oceanic and Atmospheric Administration
NR	Natural Resources (in reference to that part of the WAC that presents NR rules)
NRC	Nuclear Regulatory Council
NRT	Natural Resource Technology
NTSB	National Transportation Safety Board
NUCA	National Utilities Contractors Association
ONYX	ONYX Special Services
OSI	Ocean Surveys, Incorporated
OU	Operable Unit
OU 1	Little Lake Butte des Morts
OU 2	Appleton dam to Little Rapids dam
OU 3	Little Rapids dam to De Pere dam
OU 4	De Pere dam to mouth of the Lower Fox River
OU 5	Green Bay from the mouth of the Lower Fox River to its confluence with Lake Michigan
PAH	polycyclic aromatic hydrocarbon
PCB	polychlorinated biphenyl
PPE	personal protective equipment
ppm	parts per million
Proposed Plan	Proposed Remedial Action Plan
PRT	platinum resistance thermometer
P-wave	compressional wave
QA	quality assurance
QAPP	Quality Assurance Project Plan
QA/QC	quality assurance/quality control
QC	quality control
QL A	Quality Level A
QL B	Quality Level B
QL C	Quality Level C
QL D	Quality Level D
RAL	remedial action level
RETEC	The RETEC Group, Inc.
RI	Remedial Investigation
RI/FS	Remedial Investigation and Feasibility Study
RL	reporting limit
ROD	Record of Decision
RTK	real-time kinematics
SAP	Sampling and Analysis Plan
SAV	submerged aquatic vegetation
SBLT	sequential batch leach test
SMU	Sediment Management Unit
SOP	Standard Operating Procedure

List of Acronyms

SQL	Structured Query Language
SUE	subsurface utility engineering
TOC	total organic carbon
TRT	Technical Review Team
TSCA	Toxic Substances Control Act
TSS	total suspended solids
USACE	United States Army Corps of Engineers
USEPA	United States Environmental Protection Agency
UCL	upper confidence limit
USCS	Unified Soil Classification System
USDOT	United States Department of Transportation
USL	upper screening level
VOC	volatile organic compound
WAC	Wisconsin Administrative Code
WCM	Wet Chem Method
WDNR	Wisconsin Department of Natural Resources
WTM	Wisconsin Transverse Mercator

1 Introduction

1.1 Objectives

This Sampling and Analysis Plan (SAP) describes data collection activities necessary to properly design a contaminated sediment remedy for the Lower Fox River Operable Units (OUs) 3, and 4. This SAP has been developed concurrently with the Quality Assurance Project Plan (QAPP) to comprise the two components of the Lower Fox River Pre-Design Sediment Characterization Study (LFRPD).

Remedy options are described in two separate Record of Decisions (RODs), one for OUs 1 and 2 (ROD; WID000195481, December 2002) and another for OUs 3, 4 and 5 (WID000195481, June 2003). The RODs defined the remedial action limit (RAL) for polychlorinated biphenyls (PCBs) at a concentration of 1 part per million (ppm) for OUs 1, 3 and 4. The RODs in OUs 1, 3 and 4 require a remedial action for soft sediment with concentrations above the RAL. The RODs do not require active remediation for OUs 2 and 5. These OUs will be managed through monitored natural recovery (MNR).

The LFRPD objective is to strike a balance in the level of effort necessary to generate data essential to the appropriate engineering design for three major components of a sediment remedy; in-water (removal and capping), dewatering, and disposal. Each remedial component must be engineered with enough flexibility to efficiently operate within the expected range of conditions while understanding that each component also has its own range of uncertainty or expected conditions. Data appropriate for design of each component need to be available to reduce or refine the range of expected conditions, thereby resulting in an appropriate and cost-effective engineering design that will avoid or limit potential cost overruns and schedule delays.

The SAP and QAPP, combined with the data collected, will essentially culminate in the preparation of a Basis of Design Report (BODR) for OUs 3 and 4 and will provide adequate detail to prepare construction bid documents. For this LFRPD, Deposit DD (in OU 2) will be included as part of OU 3, and OU 4 will extend 1,500-feet into Green Bay (in OU 5). Implementation of the LFRPD will:

- Support the Wisconsin Department of Natural Resources (WDNR's) and United States Environmental Protection Agency's (EPA's) stated goal of implementing remedial actions in OU 3 and OU 4

- Provide WDNR and EPA a greater level of certainty in the volumes of material to be addressed for use as a basis in settlement negotiations and implementation of an elevation-based remedy

- Increase the confidence in describing existing Site conditions, thus reducing the potential for "changed conditions" claims by remediation contractors

- Address data needs for each major component of the remedy described in the ROD

1.2 Background

The Lower Fox River is defined as that 39-mile segment of the River beginning at the outlet of Lake Winnebago and terminating at the mouth of Green Bay (Figure 1-1). Flowing north, the Lower Fox River is the primary tributary that leads into southern Green Bay (Sullivan and Delfino, 1982) draining approximately 6,330 square miles (mi^2). The change in River elevation between Lake Winnebago and Green Bay is approximately 168 feet. A Remedial Investigation (RI) was conducted by Natural Resource Technology (NRT) in 2001, which was used in a Feasibility Study (FS) conducted by The RETEC Group, Inc. (RETEC). To facilitate the Remedial Investigation and Feasibility Study (RI/FS) activities and identify specific points along the River, the Lower Fox River was divided into the following four separate Operable Units in sequential order going downstream:

- **OU 1** Little Lake Butte des Morts
- **OU 2** Appleton dam to Little Rapids dam
- **OU 3** Little Rapids dam to De Pere dam
- **OU 4** De Pere dam to mouth of the Lower Fox River

In addition to these four OUs, OU 5 consists of Green Bay from the mouth of the Lower Fox River to its confluence with Lake Michigan. As previously stated, OU 2 and OU 5 are not considered in this LFRPD because MNR is the specified remedy in the RODs. The data collection activities necessary to support the MNR remedy are addressed in a separate Long-term Monitoring Plan (LTMP) prepared in 2003 (RETEC, 2003a).

1.3 General Descriptions of OUs

This section provides a general description of OUs 3, and 4 as they affect the LFRPD. The characteristics of each OU are thoroughly discussed in the RI/FS (RETEC, 2002a, 2002b), RODs (WDNR and EPA, 2002 and 2003), and Detailed Evaluation of Alternatives (DEA) (RETEC, 2003b). The RI/FS evaluated data from numerous historical investigations, some of which had been conducted as early as 1971. These data have been incorporated into a single Fox River Database (FRDB), which is available at the WDNR's Lower Fox River web page (http://www.dnr.state.wi.us/org/water/wm/lowerfox/index.html). The current database contains more than 580,000 analytical records captured since 1971, including substantial data collection activity from 1989 through July 2002. The FRDB includes analytical data for sediment, water, air, and biota (e.g., fish and wildlife tissues) samples.

1.3.1 OU 1

OU 1 includes all of Little Lake Butte des Morts. OU 1 extends from the Neenah and Menasha channel outlets from Lake Winnebago to Appleton lock number 1 (Figure 1-2). Covering a total area of approximately 1,400 acres, OU 1 is approximately 6 miles long (north to south), and 3,500 feet wide (east to west). This reach includes previously delineated sediment deposits A through H and POG. The total area of PCBs exceeding the 1 ppm PCB RAL is approximately 440 acres. Total contaminated sediment volume is approximately 2.2 million cubic yards (cy) containing approximately 1,850 kilograms (kg) of PCBs with nearly 98 percent residing in the top 3.3 feet of sediment. The highest detected total PCB concentration in sediment was approximately 350 ppm and the average concentration was approximately 15 ppm.

The OU 1 remedy identified addresses 784,000 cy containing approximately 1,715 kg of PCBs. Within this volume, an estimated 16,165 cy exceeds the Toxic Substances Control Act (TSCA) limit of 50 ppm.

1.3.2 OU 3

OU 3 includes Little Rapids to De Pere and extends from the Little Rapids (Kaukauna) dam to the De Pere dam (Figure 1-3). Covering a total area of approximately 930 acres, OU 3 is approximately 7 miles long (north to south), and varies in width from over 2,000 feet at the southern end to approximately 1,000 feet at the narrows before the De Pere dam. This reach includes previously delineated sediment deposits EE through HH. The majority of contaminated sediments exist in a single contiguous deposit (Deposit EE). The total area of PCBs exceeding the 1 ppm PCB RAL is approximately 320 acres. Total contaminated sediment volume is approximately 3 million cy containing approximately 1,250 kg of PCBs. The average concentration in sediment throughout the reach is approximately 6 ppm. The highest detected total PCB concentration is 54 ppm.

In addition, Deposit DD (located in OU 2) will be removed as part of the OU 3 remediation. Covering a total area of approximately 37 acres, Deposit DD contains an estimated PCB mass of 31 kg and a contaminated sediment volume of approximately 9,000 cy.

The OU 3 remedy identified addresses 595,000 cy of contaminated sediment containing approximately 1,140 kg of PCBs (including Deposit DD).

1.3.3 OU 4

OU 4 includes De Pere to Green Bay and extends from the De Pere dam to the mouth of the River at Green Bay (Figure 1-4). Covering a total area of approximately 1,300 acres, OU 4 is approximately 7 miles from north to south. This reach has been divided into 96 Sediment Management Units (SMUs), numbered 20 through 115 and 16 water column segments (6 SMUs to a segment). The SMUs and water column segments were initially established for computer modeling studies. The area for OU 4 considered for this study will extend 1,500 feet radially into Green Bay. The total area of PCBs exceeding the 1 ppm RAL is approximately 1,034 acres. Total contaminated sediment volume is approximately 8.5 million cy containing approximately 26,650 kg of PCBs. This OU also contained the highest detected PCB concentration found in the entire River (710 ppm). This area was the focus of the SMU 56/57 pilot dredging project (conducted in 1999 and 2000) which effectively removed this hot spot.

The OU 4 remedy will address 5.9 million cy of contaminated sediment containing approximately 26,400 kg of PCBs. Within that volume, an estimated 240,778 cy exceeds the TSCA level of 50 ppm.

1.4 Operational Considerations

Operational considerations that affect the LFRPD include water depths, dams, federal navigation channels, and in-water infrastructures and obstacles. These operational considerations can affect the LFRPD sample and data collection activities and will also need to be considered during remedial design.

1.4.1 Water Depth Constraints

Several data sets have been combined to generate preliminary site bathymetry and mudline elevations. These sources include data from individual sediment surveys (which recorded water depth and bathymetric transects) conducted by Ocean Surveys, Incorporated (OSI) in 1999 and sediment probing activities within the OUs. The OSI survey provides the most extensive coverage of OUs 1, 3 and 4.

Detailed project information is not available for the OSI survey data. Based upon a review of information provided, the existing bathymetric surveys do not appear to meet the United States Army Corps of Engineers (USACE) specifications for conducting construction surveys (USACE, 2002). Transects were run parallel to the shore, an average of 300 feet apart, with no apparent overlap. Nearshore depth information was not collected during the OSI surveys leaving a data gap. In addition, it is not clear whether single- or multi-beam surveys were conducted and water elevations were not recorded at the time of the surveys.

Water depth information was collected during various other sediment surveys, which also do not meet USACE specifications. Water depth data from these surveys are seldom referenced to a documented water elevation benchmark. Given the observed fluctuations in water level during the normal operation of the numerous dams on the Lower Fox River and the seiche effect in OU 4, the uncertainty associated with these data is on the order of at least 1 to 2 feet.

EPA's Field Environmental Decision Support (FIELDS) Program also conducted a bathymetric survey in OUs 1, 3 and 4 in 2002. Data have been requested, however, EPA has not released the report or data. Review of the available information regarding this survey suggests that this survey was conducted using single-beam acoustical equipment along line spacings of 30 meters that run diagonal to the River channel and were referenced to a known water elevation.

OU 1

The majority of OU 1 is less than 5 feet in water depth. Areas of deposits in the vicinity of deposits A/B, C, and POG are less than 3 feet deep. Within the central part of the River along the thalweg, depths generally range from 5 to 10 feet with a maximum depth of 18 feet at the northern end.

OU 3

The main channel depth is generally greater than 6 feet throughout most of OU 3, although there are areas in the southern end that are only 1 to 2 feet deep. The water depth is typically less than 4 feet close to the shore and drops off abruptly. At the De Pere dam, water depths reach 18 feet.

OU 4

The River is broad and shallow at the upper end, becoming narrow and deep as it approaches the mouth of the River. In the downstream portion, the federal channel has been routinely dredged to maintain a federally authorized navigation depth of 24 feet. River depths outside of the navigation channel range from 4 to 12 feet from De Pere to the Georgia Pacific (Fort Howard) Facility. Water depths downstream from the Georgia Pacific Facility to the River mouth are up to 20 feet.

1.4.2 Federal Navigation Channels

Federally authorized navigation channels exist throughout the Lower Fox River. Some of these are routinely dredged to maintain authorized navigation depths and other areas have not been dredged for decades.

OU 1

Navigation channels are indicated on the USACE plan sheets (USACE Detroit District) in OU 1 at the Menasha lock on the southern end, and the upper Appleton Lock on the northern end, and are shown on Figure 1-5.

The Menasha Channel is authorized to a depth of 6 feet, a width of 100 feet, and a length of approximately 3,400 feet into Little Lake Butte des Morts. The Menasha Channel passes through Deposit POG. On the northern end of the OU, the Upper Appleton Channel is authorized to a depth of 7 feet, a width of 100 feet width, and a length of approximately 6,000 feet southward into Little Lake Butte des Morts. The Upper Appleton Channel does not include any known PCB-containing deposits. There are no federally authorized navigation channels into Little Lake Butte des Morts. However, there is currently sufficient water depth (greater than 6 feet) to accommodate navigation needs.

OU 3

Navigation channels are indicated on the USACE plan sheets (USACE Detroit District) in OU 3 at the Little Kaukauna Lock on the southern end, and the De Pere dam on the northern end, and are shown on Figure 1-6.

OU 4

Navigation channels are indicated on the USACE plan sheets (USACE Detroit District) in OU 4 between the De Pere dam and mouth of the River as shown on Figure 1-7. The USACE currently only dredges and maintains the federally authorized navigation channel between Green Bay and the Georgia Pacific (Fort Howard) turning basin (approximately 3.4 miles). Data available on the USACE Detroit District website indicates that since 1958, an average of 63,000 cy per year was dredged from OU 4, with a range of 5,300 to 377,000 cy. Currently, all dredged material is handled at the Bayport Confined Disposal Facility (CDF). As documented in the RI, to date almost 9.4 million cy have been placed in the Bayport CDF, with the capacity for another 2 million cy of sediment.

The channel between De Pere dam and Georgia Pacific turning basin is not actively maintained. The remaining portions of the navigation channel, along with the lock and dam system, have been placed in "caretaker" status.

1.4.3 Infrastructure and Obstructions to In-Water Operations

Other infrastructures with potential to affect the LFRPD and remedial operations include transportation corridors (highway and railroad bridges), underwater pipelines, underwater and overhead cables, outfalls, and other submerged structures.

Prior to completing remedial design, in-water structures and obstructions must be understood and accurately located. This will be done using a detailed aerial survey, side-scan sonar surveys, as well as checking with the local utility firms and municipalities for the nature and activity of in-water cables and pipelines.

OU 1

Infrastructures that have the potential to impact remedial operations are shown on Figure 1-5. These include the Menasha railroad bridge, the Highway 441 Bridge, water intakes and discharge outfalls, submerged pipelines, overhead cables, and fish cribs placed by WDNR. These sources of information come from the National Oceanic and Atmospheric Administration (NOAA) chart for OU 1, as well as from a Geographic Information System (GIS) listing of structures obtained from WDNR and Winnebago County.

While not operational, the railroad bridge provides insufficient overhead clearance for a moderately sized vessel to pass underneath. The Highway 441 Bridge does not represent a barrier to in-water removal activities, but could potentially impact capping locations. The Wisconsin Department of Transportation is considering adding a second bridge south of the current one, which may need to be considered in final design.

Aerial cable crossings are indicated near deposits A/B and at the northern end of Stroebe Island. The only indicated submerged cable identified to date is identified near the upper Appleton dam.

Outfalls and submerged pipelines occur through or in the vicinity of deposits A/B, C, POG, and E. Several gas pipelines run through OU 1. The exact locations are presently being investigated. A sewer outfall runs from Menasha through Deposit POG. A pipeline runs through the southern edge of Deposit E, but the type of pipeline is unknown. Underwater structures that must be considered during dredge or cap design include existing water intake lines for Eggers Industries and Kimberly-Clark, located in Deposit A. The Eggers Industries line is abandoned but the Kimberly-Clark line is active.

OU 3

Infrastructures that have the potential to impact remedial operations in OU 3 are shown on Figure 1-6. These include submerged pipelines, overhead cables, and ruins at the southern and northern ends of the OU. These sources of information come from the NOAA chart for Little Rapids to De Pere, as well as from a GIS listing of structures obtained from WDNR and Brown County.

Aerial cable crossings are indicated south of Deposit EE. Submerged cables traverse through deposits GG and HH south of the De Pere dam.

OU 4

Infrastructures that have the potential to impact remedial operations are shown on Figure 1-7. Infrastructures include road and railroad bridges, submerged pipelines and cables, intake/discharge pipes, pilings, dolphins, and overhead cables. Most of the infrastructure occurs north of the Georgia-Pacific Facility, which includes SMUs 50 through 115. In addition, sea wall stability and the presence of several active docks in OU 4 will be considered in any remedial design.

There are seven bridges crossing the River. Physical support structures and operations need to be considered in any remedial design. These include:

- **Tower Drive – At Mile 0.41 from River Mouth.** Fixed-span four-lane I-43 Interstate highway bridge. Vertical clearance can vary depending upon fluctuations in lake level, but was built at 120 feet above high-water datum. Full channel width is available through the bridge.

- **Wisconsin Central Railroad – At Mile 1.02.** Left opening of 85 feet. Right opening of 85.6 feet. Vertical clearance of 7.5 feet. Normal position open. The crossing is unattended and is closed by train personnel only as required for train crossings. Audio and visual warnings when moving.

- **Main Street – At Mile 1.57.** Horizontal clearance of 95 feet with a vertical clearance of 14.9 feet.

- **Walnut Street – At Mile 1.8.** Horizontal clearance of 95 feet with a vertical clearance of 11.8 feet.

- **Don A. Tilleman (Mason Street) – At Mile 2.25.** Horizontal clearance of 95 feet with a vertical clearance of 32.6 feet.

- **Wisconsin Central Railroad – At Mile 2.6.** The left and right openings are each 75 feet with a vertical clearance of 8.3 feet. Unattended with normal position open.

- **Wisconsin Central Railroad – At Mile 3.3.** The left and right openings are each 75 feet with a vertical clearance of 31.1 feet. Unattended with normal position open.

Aerial cable crossings are indicated at the southern and northern ends of the OU 4. Submerged pipelines and cables frequently traverse through the northern portion of OU 4, as well as SMUs 26 to 31 and 32 to 37.

WDNR records indicate that there are 15 outfalls located along the River in OU 4. One outfall is located at the city of De Pere Sewage Treatment Facility in SMU 26, and the remainders are located north of the Georgia-Pacific Facility.

The NOAA Navigation Chart (NOAA Chart 14918) shows that there are potential barges or ships submerged in the River, as well as sites of potential archeological interest. These are shown on Figure 1-7 and include sites just north of the railroad bridge at mile 3.3 (next to the Northeast Asphalt and LaFarge North America facilities), at the Mason Street Bridge, and at and north end of the railroad bridge at mile 1.02. These will likely show up during the side-scan survey.

Shipping traffic includes approximately 200 ship-calls annually, handling principally cement, coal, limestone, salt, and asphalt (see Port of Green Bay website for details [http://www.co.brown.wi.us/solid_waste/port/index.htm]). Active docking facilities, as indicated by the Port of Green Bay, are shown on Figure 1-7. Turning basins include the confluence of the Lower Fox and East rivers and above the Wisconsin Central Railroad Bridge.

1.5 River Characteristics

This section contains a description of the geological and hydrogeological conditions, flood flow capacities, and habitat considerations.

1.5.1 Geological and Hydrogeological Conditions

The current understanding of the regional geological and hydrogeological conditions is documented in Section 3 of the RI (RETEC, 2002a). The Lower Fox River is documented to have either relatively nonporous clay or bedrock underlying most of the River. An attempt will be made to collect core samples of this underlying material for the LFRPD. Based on the fine-grained glacial deposits which underlie the Lower Fox River and the absence of regional groundwater extraction, there is little groundwater recharge from the Lower Fox River into the upper aquifer. Available information also indicates little potential seepage (advection) due to groundwater flow.

The Lower Fox River sediment grain size distribution reflects the mixture of sand, silt, and clay comprising the native silty clay glacial till deposits of the area. Sand and silt are the dominant grain sizes in Lower Fox River sediments, typically accounting for 75 to 90 percent of the particle sizes present.

Atterberg limits data collected during the 1993 and 1998 sampling activities characterized the sediments by high liquid and plastic limits. Under the Unified Soil Classification System (USCS), the majority of the sediments were classified as high-compressibility silts (MH) while a small percentage were classified as highly plastic clays (CH).

1.5.2 Flood Flow Capacity

Remedial alternatives for the Lower Fox River have the potential to influence flood flow capacity. Chapter 116 of the Wisconsin Administrative Code (WAC), Wisconsin's Floodplain Management Program, details the regulations for construction and development in floodways and floodplains. Natural Resources (NR) 116 requires that an in-water construction (including a cap) would be required to undertake a determination on the potential effects on the regional flood heights. This would require a substantive study on the hydrologic and hydraulic conditions pre- and post-construction to determine if there would be an increase in flood height due to any potential cap placement. NR 116.03(28) defines an "increase in regional flood height" as being equal to or greater than 0.01 foot. Flood flow capacity issues relating to implementation of a capping remedy are thoroughly discussed in *White Paper No. 6B – In-Situ Capping as a Remedy Component for the Lower Fox River* (appended to the Responsiveness Summary for OUs 1 and 2, Palermo et al., 2002).

The increase in regional flood height is an issue that may significantly impact the ability to implement a capping remedy. Potential capping areas in each OU were first determined based upon the areas where the PCBs exceeded the 1 ppm remedial action level, and a clear, post-construction water depth of at least 3 feet could be achieved. The ROD for OUs 1 and 2 was constrained such that only 25 percent of the volume of contaminated sediments could be capped. The DEA (RETEC, 2003b) identified the maximum areas where capping could be considered. Additional constraints to capping included the presence of PCBs greater than 50 ppm, and presence of the federal navigation channel. Areas that met these criteria are indicated on Figures 1-5, 1-6, and 1-7 for OUs 1, 3, and 4, respectively. These criteria will be re-applied following bathymetry and side-scan sonar data collection activities (described below) to refine the potential capping areas. The DEA preliminarily identified approximately 220, 80, and 270 acres of potential capping areas in OUs 1, 3, and 4, respectively.

1.5.3 Gas Formation

The Lower Fox River has high methane sediment content (GAS/SAIC, 1996). Sub-bottom profiles of sediments revealed large subsurface accumulations of methane in OUs 1 and 3. Methane releases have been frequently observed during sediment sampling and were seen during the demonstration project at

SMU 56/57. Recognizing the potential for methane to affect sub-bottom profiling, this technique will be limited to delineation of the lateral (i.e., x, y) extent of soft sediment deposits. It is unlikely that sub-bottom profiling will provide adequate data to delineate the total thickness of soft sediment deposits.

1.5.4 Habitat Considerations

Habitat considerations are important for the LFRPD because submerged aquatic vegetation (SAV) can affect acoustical survey work and dredging or capping can disrupt critical fish habitat areas. The RODs for the various operable units have clearly identified that remediation within sensitive habitats will not be considered.

OU 1

Major habitat areas identified within the RI included the Stroebe Island Marsh and backwater areas (Figure 4-1, RETEC, 2002a). In OU 1, the marshland around Stroebe Island has been identified by the WDNR as a valuable spawning habitat for bluegill, sunfish, bass, and northern pike. Reports of SAV in OU 1 included pondweed, waterweed, eelgrass or water celery, and water lilies. These species are located on the shallow edges and backwater coves. Large cattail stands are also identified near Stroebe Island where Mud Creek enters the Lower Fox River. The last remnant of a northern pike spawning marsh is located along the inside (west side) of Stroebe Island. Northern pike is an important predator species and WDNR has indicated that this spawning marsh should be protected from future dredging or fill (WDNR, 2002). A detailed discussion of the habitat within OU 1 and the potential impacts associated with remedial actions, may be found in *White Paper No. 8 – Habitat and Ecological Considerations as a Remedy Component for the Lower Fox River* (appended to the Responsiveness Summary for OUs 1 and 2, WDNR, 2002).

OU 3

The RI identifies little wetland, nearshore SAV, or in-water habitat identified within OU 3. This is likely because the River is narrower with faster stream flow velocities, conditions that are not favorable for the establishment of SAV. No specific fish spawning areas have been identified for OU 3.

OU 4

The RI and the Baseline Human Health and Ecological Risk Assessment indicate that there is very little nearshore habitat within OU 4 (RETEC, 2002c). There are some smaller wetlands and/or SAV at the southern end of the reach near the Brown County Fairgrounds below the De Pere dam; otherwise the River is heavily channelized with riprap or industrial use along the water edge. Notwithstanding this, there is a considerable influx of fish into the reach from Green Bay. These especially include walleye, perch, sturgeon, carp, and several species of forage fish. WDNR has installed spawning cribs for walleye in the southern end of the reach.

1.6 Sediment Thickness

As discussed briefly above, sub-bottom profiling has been attempted on the Lower Fox River to determine depth of soft sediment. However, because of the presence of substantial amounts of methane gas, this technique has limited utility. In development of PCB mass and sediment volume estimates for the RI, interpolated grids were developed for the depth of sediment, PCBs, and other environmental parameters in the Lower Fox River. Similar to the bathymetric discussion above, many sources of data were assembled to develop these grids. As with the bathymetry contours, data from each of these data sets contained inherent uncertainty, which is often of unquantifiable magnitude. Data sets used to develop these interpolations often used different methods to define the extent of soft sediment, different locational techniques with variable accuracies, were relative only to the sediment-water interface and spanned several years while not accounting for changes in sediment bed elevation. Although all of these issues contribute to the overall uncertainty associated with the delineation of the remedy prism, the resulting bed maps do provide useful insight for the planning of the extent and scale of the activity to be undertaken.

1.6.1 OU 1

Current sediment thickness maps for OU 1 (Figure 1-8) are based principally on the relatively sparse poling data collected as part of the Green Bay Mass Balance Study, as well as information from focused sediment investigations in individual deposits as recent as 2002. These deposits cover about 770 acres and thickness ranges up to approximately 6.2 feet.

1.6.2 OU 3

Soft sediment thickness maps for OU 3 are presented on Figure 1-9. These deposits cover about 660 acres with soft sediment thickness ranging up to approximately 7.5 feet thick. For much of Deposit EE, the soft sediment accumulation is between 3 and 4 feet. The deposits immediately behind the De Pere dam have greater accumulations, between 4 and 7.5 feet.

1.6.3 OU 4

OU 4 is almost a continuous deposit of sediment that extends from the De Pere dam to the Georgia-Pacific turning basin (Figure 1-10). These deposits cover about 1,300 acres and thickness ranges up to almost 20 feet. Downstream of the turning basin, sediments are routinely removed by dredging operations conducted to maintain the navigation channel. Sediment thickness is typically up to 4 feet in the southern portion of the OU. In the middle section of the OU, large areas of the River bottom are covered by sediment thicker than 6 feet.

1.7 LFRPD Approach

In 2001, WDNR and EPA decided to perform additional refinement of select remedial technologies and process options identified in the FS. In early 2002, RETEC was contracted to convene a Technical Review Team (TRT) and conduct a detailed evaluation of remedial alternatives. The TRT conducted an intense evaluation of several aspects of remedial implementation and provided several broad recommendations. These recommendations are particularly important as multiple possible remedies were considered, and represent the minimum additional information that is needed to develop detailed engineering and design plans. The TRT concluded:

- The estimate of the in-place volume and acreage of sediment that exceeds the 1 ppm remedial action level should be refined through additional sampling. This sampling program may be based on a geostatistical evaluation of PCB spatial variability (vertical and horizontal) across the project area by defining SMUs within each Operable Unit and sampling within those units.

- The vertical extent of PCBs in excess of the 1 ppm action level should be expressed as a “cut elevation” to define the limits of any dredging that may occur. PCB sample points need to be converted to a common and reproducible survey datum. Sampling points should also be accurately located in the x, y, and z dimension so that post-remediation samples can be collected at the same points. (In general, current technology allows for lateral reproducibility to within 1 meter.)

- Additional sediment physical data is needed for select reaches of the River to further determine the mass of dry solids that will result from removing in-place deposits and for designing handling and dewatering systems. The tests include total solids, bulk density, grain size distribution (sieve and hydrometer), and specific gravity (of the solids).

- Additional geotechnical testing is needed to improve the confidence level in sizing possible disposal facilities (as well as dewatering equipment). The tests include routine Atterberg limits, column settling tests, consolidation tests, and shear strength tests.

Based on the recommendations of the TRT and RETEC’s subsequent DEA (RETEC, 2003b), the data needs have been identified for final engineering on a range of potential Site remedies including capping and/or mechanical dewatering for landfill disposal. The testing plan consists of three primary activities; base mapping, delineating the 1 ppm PCB remedy prism, and engineering/geotechnical analyses. Each of these primary activities includes a series of definitive tasks, which address data needs identified by the TRT. The tasks related to each primary activity, which are discussed in detail in subsequent sections of this SAP:

- **Base mapping activities** to provide the necessary information for subsequent bathymetric surveying allowing all project data to be presented on a common output, includes:
    - Topographic surveying to provide elevations and contours of upland areas used for staging support facilities
    - Survey controls (x, y, and z) located throughout each OU which will be used for all subsequent phases of remedy design and implementation
    - Bathymetry to determine Site limitations of select remedial designs and limitations presented in the FS and RODs
    - Side-scan sonar to assist in the delineation of the lateral extent of soft sediment for the 1 ppm PCB remedial prism delineation activity and to locate debris and obstructions
    - Sub-bottom profiling to assist in the delineation of the lateral extent of soft sediment for the 1 ppm PCB remedial prism delineation activity
- **Delineating the 1 ppm PCB** remedial prism to refine the estimates and locations of sediments to be remediated, includes:
    - Sediment core sampling
    - Identification of statistical processes to determine adequate sample densities
- **Engineering/geotechnical analyses** to determine *in-situ* physical characteristics, dewatering and water treatment requirements, along with sediment handling properties to properly design removal, disposal, or capping components of the final remedy
    - Shear strength (*in-situ* sediments)
    - Upland borings and standard penetration tests

- Compressive strength and Proctor test for dewatered solids
- Preliminary disposal and materials handling characterization tests
- Column settling tests
- Belt press and filter press tests
- Jar testing for wastewater treatment
- Leach tests

This LFRPD SAP, in its entirety will be implemented in OUs 3, and 4 Limited portions of this LFRPD, specifically the base mapping activities only, will be implemented in OU 1. The remaining characterizations in OU 1, PCB delineation and engineering/geotechnical characterizations, will be completed under an Administrative Order on Consent between USEPA, WDNR and certain responsible parties.

Additional project detail which supports this LFRPD SAP can be found in the companion document: Lower Fox River Pre-Design Sediment Characterization Study: Quality Assurance Project Plan (QAPP).

2 Field and Laboratory Methods

2.1 Base Mapping and Survey Control

Accurate topographic and bathymetric surveys are required to develop a base map in support of final engineering design and to provide an accurate representation of all project data. Specifically, the mapping will be used for the following:

- Finalizing the pre-remediation sediment elevation (i.e., plans and specifications survey, per USACE terminology)
- Plotting pre-design sample locations on a uniform x-y-z coordinate system
- Generating revised dredge volume estimates
- Characterizing of public and private shoreline features that may be impacted by remedial work (docks, bulkheads, etc.)
- Providing a large-scale base map upon which utility data, derived from outside sources, can be accurately shown
- Providing a construction base map for project infrastructure and facilities (docks, slurry piping, dewatering plant, wastewater treatment plant, etc.) that will be part of the remedial action
- Establishing a construction grid system upon which construction documentation and pay quantity determinations will be based

Minimum requirements for the topographic survey and mapping effort, along with the corresponding survey control, are described in the following subsections. The bathymetric surveying and related activities are described in Section 2.2.

2.1.1 Topographic Surveying and Mapping

Aerial photography to support the topographic map will consist of approximately 3000 acres in OU1, approximately 1600 acres in OU3, and approximately 2800 acres in OU4. At each OU, the aerial coverage at a minimum will range up to several hundred feet in from the shoreline, generally to the nearest public road. This will provide a base map for the development of riverfront support facilities.

The aerial photography will be acquired by KBM, Inc. under supervision of Jenkins Survey and Design, Inc. (JSD). In addition, topographic mapping procedures will be managed by JSD. Procedures for surveying and mapping will follow the general guidelines and suggested practices in USACE EM 1110-1-1000, *Photogrammetric Mapping* and USACE EM-1110-1-1005, *Topographic Surveying*. The resulting mapping will conform to National Mapping Accuracy Standards for Topographic Surveying and photo control on field targets will be provided with Trimble 4800 Global Positioning System (GPS) survey equipment. Specifications for this project include the following:

Coverage	• Entire length of shoreline at OU 1, 3 and 4. • For OU 1 and OU 4, coverage shall extend inland to the nearest public road, which is expected to result in a width ranging from 200 to 1,000 feet. • Coverage in OU 4 will extend north into Green Bay 1,500 feet. • At the south end of OU 1, coverage shall extend to the railroad tracks, spurs, and access road south of Bergstrom fill. • For OU 3, on the east side of the River, coverage shall extend inland to the former railroad tracks, east of Highway 32/57. Coverage in OU 3 will also extend south into OU 2 to cover Deposit DD.
Equivalent Target Map Scale	1 inch = 50 feet (**Note:** The mapping will also be used at various smaller scales for different purposes on the project, but the accuracy of the aerial survey shall be based on a map scale no smaller than 1 inch = 50 feet.)
Feature Location Tolerance	0.5 foot
Horizontal Control Survey Type	Third order, Class I
Feature Elevation Tolerance	0.2 foot
Vertical Control Survey Type	Third order
Map Contour Interval	2 feet
ASPRS Map Accuracy	Class 1
Horizontal Coordinate System	Wisconsin Transverse Mercator (WTM) 83
Vertical Datum	North American Vertical Datum (NAVD) 88
Unit of Measure	U.S. survey foot
Output Electronic Format	Compatible with ArcGIS and AutoCAD
Output Hard Copy Format	American National Standards Institute (ANSI) D-size sheets (22 × 34 inches) (to allow half-scale plotting directly to 11 × 17 inches when needed)

2.1.2 Survey Control

The project will require the placement of permanent nearshore survey monuments to establish vertical and horizontal project control. Existing USACE or National Geodetic Survey (NGS) monuments may be used as part of the survey control network to the extent practical. The network shall be in place at the time of the initial base mapping described above and will later be used for construction documentation and long-term monitoring.

Monumentation will follow the guidelines and suggested practices of USACE EM 1110-1-1002, *Survey Markers and Monumentation*. The general requirements for this network include the following:

Coverage	• Monuments set every 0.5 to 1 mile, with temporary reference points at intermediate locations as needed
Siting Criteria	• On public land, or by agreement with and unobstructed access from municipal or industrial owners • On private land (only if necessary) by agreement with owners • Clearly visible from upstream and downstream locations on the water • Located at, or in close proximity to, water's edge, allowing future placement and routine calibration of tide gauges (for dredge process control) • No overhead obstructions that would impede GPS readings
Accuracy	Third order
USACE Monument Type	• On stable, existing concrete structures – Type C (metal disk) • In granular, fine-grained, or glacial soils with high bearing strength – Type F (disk on shallow rod) or Type G (disk in cast-in-place concrete)
Vertical Datum	NAVD 88
Horizontal Coordinate System	WTM 83

2.2 Geophysical Surveys

An initial series of geophysical surveys will be conducted to determine the physical characteristics of sediment throughout OUs 1, 3, and 4. These surveys will include bathymetric surveys, side-scan sonar surveys, and sub-bottom profiling surveys. The bathymetric survey will map sediment bed elevation, while the side-scan sonar survey will map sediment transition zones and the location of submerged obstructions. In addition, the sub-bottom profiling survey will confirm sediment transition zones by providing sediment stratigraphy.

2.2.1 Bathymetric Survey

A bathymetric survey will be conducted in order to provide a baseline set of sediment bed elevations. The elevations will be entered into the project database and utilized for the remedial design as well as the LTMP. The survey will be performed by ONYX Special Services (ONYX), in accordance with the Standard Operating Procedures (SOP) for single-beam and multi-beam bathymetric surveys included in Appendix A. Table 2-1 summarizes the standard equipment specifications and output requirements to be achieved by the bathymetric surveys.

RETEC proposes to use ONYX to acquire the bathymetric surveying data. ONYX will conduct the survey by the use of a multiple transducer, single-beam sweep system manufactured by Ross Laboratories, Inc. The sweep system will employ three single-beam transducers mounted on each of two symmetrical booms across the vessel's midsection. In addition two transducers will be mounted to the hull of the vessel. All transducers will be spaced at 5-foot intervals thus; eight bathymetric soundings will be recorded across a 35-foot swath at any given ping location. Each acoustic transducer is tuned to operate at a single frequency of 200 kilohertz (kHz), providing an optimal vertical resolution of 0.10 foot. The average vertical accuracy for each transducer is 0.10 foot plus or minus (±) 0.10 percent of the water depth (e.g., accuracy of 0.15 foot in 5-foot water depths). Absolute vertical resolution and accuracy are highly dependent on sediment type, river bottom slope, and transducer beam angle.

Bank-to-bank coverage will be achieved by surveying an initial track parallel to the shoreline at the shallowest possible water depth, followed by a series of survey lines parallel to shore spaced at approximately 40-foot intervals. A second series of transects will be surveyed perpendicular to shore at approximately 100-foot intervals in order to provide cross lines for data quality control. A minimum of 2,900 bathymetric readings will be acquired per survey acre, providing a 3-foot by 5-foot data point grid.

High-resolution bathymetric data will be acquired over features demonstrating particularly high relief or extreme bed elevation change by use of a multi-beam swath system in water depths greater than 6 feet. The multi-beam data will provide a more detailed representation of absolute sediment elevation, due to the higher number of acoustic returns over a wider swath. This secondary bathymetric survey is contingent upon the results of the single-beam survey and will be performed by ONYX in accordance with the SOP included in Appendix A. ONYX will use a SeaBat 8125 ultra high-resolution multi-beam sonar system manufactured by RESON, Inc. The SeaBat 8125 utilizes 240 dynamically focused receive beams to achieve an optimal vertical resolution of 0.02 foot. SeaBat 8125 operating specifications are summarized in Table 2-1. Survey line spacing will be determined on a location-specific basis in order to provide full coverage of each feature.

Horizontal positioning for the survey vessel and bathymetric sensors will be maintained by employing Real Time Kinematics (RTK) procedures that will receive signal corrections from a shore-based unit. The average accuracy for such systems is ±0.03 foot for horizontal positioning, and ±0.10 foot for vertical positioning. The horizontal positioning data will be transmitted in real time to an onboard vessel tracking system, such as HYPACK. HYPACK displays significant features such as river shoreline, navigational obstructions, proposed survey tracks, and the position of the vessel in relation to these features allowing the helmsman to maneuver the vessel accordingly.

The bathymetric data will be used to calculate sediment elevations. These elevations will be in reference to the precisely measured elevations of a series of shore-based benchmarked elevations (Section 2.1), and will account for variability in water elevation during survey operations. All bathymetric data sets will be gridded and incorporated into a series of digital terrain models (DTMs) and elevation contour base maps.

2.2.2 Side-Scan Sonar Survey

A side-scan sonar survey will be conducted by ONYX in accordance with the SOP included in Appendix A. The goals are to map sediment transition boundaries and determine the presence of submerged obstructions and/or archaeological artifacts. Identifying sediment transition boundaries between soft sediments and underlying bed materials will assist with the delineation of the lateral extent of PCB-contaminated sediments.

The survey will be performed in two phases by use of high-resolution, single-frequency side-scan sonar systems manufactured by Marine Sonics Technology, Ltd., operating at a low frequency of 600 kHz and a high frequency of 1,200 kHz. Acoustic imagery will be obtained along longitudinal survey lines parallel to the shore. Bank-to-bank side-scan coverage will be achieved by acquiring multiple survey lines with overlapping coverage. A typical side-scan swath can be calculated at approximately 20 times the distance between the transducer and the riverbed. Side-scan transducers operating at higher frequencies typically have a smaller maximum swath. Table 2-2 provides the standard range values and resolution for each transducer that may be used in the side-scan sonar survey.

An initial phase survey operation will employ the lower frequency side-scan transducer, 600 kHz, to achieve full coverage. An initial side-scan survey tract will follow the shore at the minimal operable water depth. In addition, a series of survey lines will generally follow uniform elevation contours, and will be adequately spaced to achieve a minimum of 15 percent overlap. Contingent upon the results of the initial survey, a second phase survey operation may employ the higher frequency side-scan transducer, 1,200 kHz, to achieve higher-resolution imagery of areas not clearly defined in the initial survey.

Horizontal and vertical positioning of the survey vessel and side-scan transducers will be maintained in the same manner as discussed in Section

2.2.1 for the bathymetric survey. The acoustic imagery will be processed and interpreted to graphically represent the physical characteristics of the riverbed (i.e., sediment type and transition boundaries) and location of obstructions to be avoided. Digital mosaics will be generated and incorporated in the project database with the baseline bathymetric data. These data will be used to assist in identifying the lateral extents of soft sediment and to aid in remedial design engineering.

2.2.3 Sub-Bottom Profiling

A sub-bottom profiling survey will be conducted by ONYX in accordance with the SOP included in Appendix A. The goals are to further identify the lateral extent of sediment types identified by the side-scan sonar survey and provide a high-resolution image of the subsurface stratigraphy. This data will provide information regarding the vertical extent of the soft sediment transition to hard sediment horizon in the subsurface.

ONYX will use a multi-frequency chirp sub-bottom system manufactured by EdgeTech, model SB-216S, which scans between frequencies of 2 and 16 kHz. Table 2-3 summarizes the general specifications of the SB-216S. The sub-bottom profile survey will be conducted concurrently with the side-scan sonar survey. Therefore, the same survey line spacing will be implemented for sub-bottom profiling as described in Section 2.2.2 for side-scan sonar. Likewise, horizontal and vertical positioning of the survey vessel and sub-bottom profiler will be maintained in the same manner as discussed in Section 2.2.1 for the bathymetric survey.

The sub-bottom profile data will be processed and interpreted to graphically represent the sediment horizon. Longitudinal profiles will be generated and incorporated in the project database with the bathymetric and side-scan sonar data sets. These data will be used to assist in identifying the lateral and vertical requirements for sediment sampling and aid in remedial design engineering.

2.2.4 Utility Location

This activity is undertaken primarily to satisfy the provisions of Wisconsin Statute 182.0175: *Damage to Transmission Facilities* protocol governing excavations, and 84.063: *Guide to Utility Coordination*. These statutes details a specific protocol for planning, notification of the one-call system, and providing specific details regarding the activities. The intent of this activity is to search for and depict utilities according to the national standard published by the American Society of Civil Engineers and its associated Construction Institute (ASCE) C/I ASCE 38-02 (ASCE, 2002). entitled This section summarizes the utility location activity and the level of effort necessary to complete this task for the LFRPD in OUs 3 and 4.

The ASCE classification system is recognized by the American Society of Civil Engineers (ASCE), the National Transportation Safety Board (NTSB), United States Department of Transportation (USDOT), subsurface utility engineering (SUE) professionals, United States Department of Transportation Federal Highway Administration Office of Program Administration (HIPA), Federal Highway Administration (FHWA), American National Standard Institute (ANSI), Associated General Contractors of America (AGC), National Utilities Contractors Association (NUCA), and the Nuclear Regulatory Council (NRC).

The level of effort for this task will adhere to the basic concepts already in place in SUE profession, found at the FHWA website (http://www.fhwa.dot.gov/infrastructure/progadmin/sueindex.htm), and will be prepared in a manner equivalent to SUE specifications. The following definitions are contained within the ASCE standard C/I ASCE 38-02 (ASCE, 2002).

- Quality Level D (QL D): Information derived from existing records or oral recollections.

- Quality Level C (QL C): Information obtained by surveying and plotting visible above-ground utility features and by using professional judgment in correlating this information to QL D information.

- Quality Level B (QL B): Information obtained through the application of appropriate surface geophysical methods to determine the existence and approximate horizontal position of subsurface utilities. QL B data should be reproducible by surface geophysics at any point of their depiction. This information is surveyed to applicable tolerances defined by the project and reduced onto plan documents.

- Quality Level A (QL A): Precise horizontal and vertical location of utilities obtained by the actual exposure (or verification of previously exposed and surveyed utilities) and subsequent measurement of subsurface utilities, usually at a specific point. Minimally intrusive excavation equipment is typically used to minimize the potential for utility damage. A precise horizontal and vertical location as well as other utility attributes is shown on plan documents. Accuracy is typically set at 15mm vertical, and to applicable horizontal survey and mapping.

The Quality Level for the utility location in the LFRPD is to achieve Quality Level B. The following steps developed by the ASCE, which are a recognized protocol for disclosing underground utilities at critical facilities, will be taken to provide the required level of quality for the OU 3 and 4 remedial design activities.

- Step One: Obtain QL B utility data within a corridor along the perimeter of the remediation corridor to identify those utilities transitioning the remedial boundary.

- Step Two: Reference this QL B data to recoverable survey control. Map onto existing background files for visual reference.

- Step Three: Identify or gather additional information on the character of "unknown" utilities through QL A data.

- Step Four: Review all data and determine applicable safety measures

- Step Five: Keep mapping available for future use by authorized persons.

In adherence to the ASCE standard C/I ASCE 38-02 (ASCE, 2002), the following provisions will also be met:

- The project owner will be responsible for taking appropriate actions to consider and deal with utility risks. Due to the magnitude of this project, the standard suggests employing the services of an engineer to provide expert advice and to use available technologies to provide better information.

- The engineer will advise the project owner of utility risks and recommend an appropriate quality level of utility data for this project area at the appropriate time within the project planning and design process. Such advice will take into account such items as type of project, expected utilities, available rights-of-way, project timetables, and so forth.

- The project owner will specify to the engineer the desired quality level of utility data.

- The engineer will furnish the utility quality level recognized by ASCE as QL B to the owner in accordance with the standard of care.

- The engineer will be responsible for negligent errors and/or omissions in the utility data for the certified utility quality level.

2.3 Sediment Sampling

The most important component of the pre-design characterization is the delineation the 1 ppm dredge elevation. This is important not only for remedial design, but also for providing an accurate remediation cost to the Responsible Parties. To accomplish this delineation a two-phased approach will be implemented in OUs 3 and 4.

2.3.1 Phase 1

Phase 1 will consist of sampling the areas shown to have soft sediment deposits on a triangular grid at an approximate rate of one core per acre. In addition, Phase 1 will include placing a series of sample clusters throughout each OU to provide necessary data on near-field lateral variability. These clusters will consist of 4 additional cores centered on a planned core location. Additional discussion of the clusters, their geometry, and orientation is provided in Appendix B. For preliminary planning purposes, the one core per acre samples will be distributed within the previously defined deposits on a triangular grid with grid nodes 230 feet apart. Final adjustment to locations of cores and the total number of cores collected in Phase 1 is dependent on completing the Geophysical Surveys discussed above.

OU 3

OU 3 will be the first area sampled. Approximately 660 acres of OU 3 and 37 acres in Deposit DD are covered with soft sediment deposits although the Geophysical Surveys discussed in Section 2.2 will re-define these areas. Preliminary sample locations and clusters in OU 3 are shown on Figure 2-2.

OU 4

OU 4 will be the last area sampled. Approximately 1,300 acres of OU 4 is covered with soft sediment deposits although the Geophysical Surveys discussed in Section 2.2 will re-define these areas. Preliminary sample locations and clusters for OU 4 are shown on Figure 2-3.

2.3.2 Phase 2

To maximize the usefulness of samples in Phase 2, results from Phase 1 sampling will be used to determine locations where additional samples will be located to reduce the uncertainty around the 1 ppm PCB delineation. In addition, this evaluation will identify areas where there is adequate confidence in the 1 ppm PCB delineation.

In general, for the triangular grid pattern employed in Phase 1, this is done by considering each triangle cell individually and applying several criteria. First we only consider triangles in which the mean PCB estimate is below the threshold value of 1 ppm and the upper confidence bound is above 1 ppm.

Next, we will consider what the impact of adding an additional sample point to the center of the triangle has on the estimate of the Standard Error (SE). Using variograms developed from Phase 1 and the cluster samples, an estimate of SE reduction can be determined. Applying this adjustment to the confidence interval over the triangle will determine whether the upper confidence limit might be reduced below 1 ppm, thus eliminating the grid cell from the remediation area. Areas that meet this condition will be the focus of Phase 2 sampling. Additional detail on the statistical basis for placement of Phase 2 cores is presented in Appendix B.

The total number of delineation core locations is not expected to exceed four cores per acre, including cluster samples and QC samples. After Phase 1 is completed and data analyzed, an addendum to this SAP will detail the results and provide Phase 2 sample locations. Phase 2 sampling will only be for refining the PCB delineation; no engineering, geotechnical, or physical samples are anticipated for Phase 2.

2.3.3 Sample Collection Methodology

A SOP for sample collection is included in Appendix A. The SOP covers sample location, securing of the sampling vessel at a station position, and includes the stepwise procedure for the deployment and retrieval of the vibracore, and subsequent sediment collection. After selecting the subcontractor, this SOP may be modified. Accurate definition of the 1 ppm PCB prism is highly dependent on vessel location and sample recovery. Historical data from the Lower Fox River system has shown that core recoveries are as low as 60 percent. Technology for collecting core samples has recently advanced to the point where 90 percent recovery can be expected for most sample types. To prevent preclusion of any emergent technologies, a performance-based specification will be written in the request for proposal to potential sampling subcontractors. The specifications that will be required include:

- Ability to attain and maintain station position: use of spuds is preferred over anchoring especially in OUs 3 and 4
- Station location: less than 1 meter (x, y) using DGPS (Differential Global Positioning System) utilizing monuments discussed in Section 2.1
- Depth measurement with water level correction: less than 5 centimeters (cm) (z) referenced to NAVD 88
- Coring equipment: vibracore or equivalent
- Recovery/penetration: greater than 90 percent;

- Ability to document rate of penetration
- Ability to collect a minimum of 12 acceptable cores per day
- Ability to collect core samples down to the native clay layer (i.e., up to 20 feet)

As described further in Appendix A, upon collection of a sediment core sample, approximately 2 cm above the apparent sediment-water interface of the sample tube liner a hole will be drilled into the liner to remove overlying water. The overlying water may contain colloidal or flocculent materials that are decanted off with the overlying water. The hole is drilled 2 cm above the apparent sediment surface to allow for some consolidation of the densest materials. The core sample should be transported from the sample location to the processing facility only in an upright position if not immediately processed on vessel.

This SAP and the QAPP will be amended to include SOPs after contractors are selected.

2.3.4 Sample Numbering Scheme

Each sample collected during the investigation will be given a unique identification code. Each unique sample identification code will consist of the following:

- **Project Identification Code.** A one-number designation will be used to identify the OU from which the sample was collected as follows:
  - **3** OU 3 (including Deposit DD)
  - **4** OU 4 (including limited sampling in OU 5)
- **Location Code.** Each sample will be identified by four digits representing the sediment coring location:
  - **XXXX** sediment coring location
- **Subsectioning Core for Multi-Sensor Core Logger (MSCL).** Each core will be sectioned into 130 cm sections for scanning with the MSCL. Sections will be identified as:
  - **M1** 1st Section
  - **M2, etc.** 2nd Section

This designation will be dropped after the core is split into 10-cm intervals. Therefore, Section M1 will become intervals A through M, M2 will become N through Z, M-3 will become AA through MM, etc.

- **Depth Code.** Lastly, each sample will be identified by a letter representing the 10-cm elevation interval sampled. After 26 10-cm intervals are reached in a core, the designation will begin with AA until the end of the core is reached. The actual elevations corresponding to each 10-cm interval would be recorded in the Sample Control Log:

  - **A** sample start at surface elevation, sample end 10-cm deeper, (0 to 10-cm)
  - **B** sample start at end of A, sample end 10-cm deeper (10-20 cm)
  - **C** sample start at end of B, sample end 10-cm deeper (20-40 cm)
  - **D** sample start at end of C, sample end 10-cm deeper (40-80 cm)
  - **E** sample start at end of D, sample end 10-cm deeper (80-100 cm)
  - **F** sample start at end of E, sample end 10-cm deeper (100-120 cm)
  - **G–ZZ** sample start at end of F, sample end 10-cm deeper, etc.

- **Example**

  30005B sediment sample from OU 3, core location 0005, 10-20 cm section

Resultant samples (e.g., mini-cores, pore water samples, leachates) will be identified in the Sample Control Log and on chain of custody forms. Each resultant sample will be tied back to the core section.

2.4 Core Processing

Core processing will take place off-site in a secure, dedicated facility, near the laboratory. Cores will be logged in electronically on the vessel. Information recorded on the vessel will include:

- Sample number (sample number scheme is outlined above)
- Date
- Time the core was collected
- Location data (x, y, z)
- Water depth (to nearest 5 cm)
- Penetration distance into sediments (to nearest 5 cm)
- Length of core recovered
- Core description (using modified American Society for Testing and Materials (ASTM) methods, see Appendix A)
- Personnel collecting core sample
- Notes

After the core is collected, logged, and described in the field, electronic data will be transmitted through the project website to the shore station, while the core is en route to the core processing facility. Based on pre-determined sampling requirements for each sample, the sample labels will be printed before subsampling the core. This will ensure that proper subsampling and/or compositing occurs for each core.

All core subsampling will occur in a dedicated core processing facility. The processing facility will be a separate warehouse-type building that is climate controlled and secured. The facility will be equipped with necessary space and devices to perform analyses (i.e., the MSCL), and subsampling of core samples. Refrigerator and freezer space will be available to ensure proper storage and handling of cores and subsamples.

The dedicated facility will be equipped with space and equipment for air-drying samples.

All cores collected for dredge prism determination will first be sectioned into 130 cm sections and scanned with the MSCL. Cores will be cut into 130 cm sections using a reciprocating saw or similar device. A thin layer (i.e., less than 0.125 inch will be scraped from the surfaces of each core section that comes into contact with the saw blade prior to sub-coring (if applicable) or drying. The top 10-cm section from each core will be archived without drying.

After scanning with the MSCL and any sub-coring procedures, core liners will be removed and the core will be cut into 10-cm sections. Some of the 10-cm sections will be sub-cored for other geotechnical or engineering data collection.

Samples will then be air-dried. After air-drying, samples will be stored in doubled plastic Ziploc® bags. The sample label will be placed on the inside bag as well as the outer bag.

Ziploc® bags are an appropriate and economical alternative to the standard practice of using glass containers. Ziploc® bags eliminate the safety hazard associated with container breakage when freezing samples for long-term storage. During previous Lower Fox River sampling events, many sample jars broke when initially frozen. Standard practice was to transfer the frozen sample material into Ziploc® bags until thawed prior to analysis. Results from these samples have demonstrated that samples contained in Ziploc® bags have not exhibited interferences with phthalates. These data have been third party validated to confirm that phthalate interference problems were not identified. In the event phthalates should present a problem during this sampling, analyses without detectable levels of PCBs would detect interference in these samples and appropriate corrective action can be implemented.

2.5 Non-Destructive Testing Program

The dedicated core processing facility will be equipped with a GEOTEK MSCL. The MSCL enables a number of non-destructive geophysical measurements to be made on un-split (whole round) sediment cores encased in cylindrical plastic core liners.

The primary measurement sensors used on the MSCL are as follows:

- **Acoustic Transducers –** measure the velocity of 500-kHz compressional waves (P-waves) in the core.
- **Gamma Ray Source and Detector –** measure the attenuation of gamma rays through the core to provide density/porosity values.

- **Displacement Transducers –** measure the diameter of the core and enable calculation of P-wave velocity and density by accounting for changes in the core diameter.

- **Platinum Resistance Thermometer (PRT) –** measures temperature during the logging process, which is particularly important for P-wave velocity calculation.

At this point, it is anticipated that only the gamma ray source and detector will be used to scan the core to save sampling time. All PCB-delineation cores will be subject to scanning for bulk density at 1-inch intervals. If it is later decided to make other measurements with the MSCL, this SAP will be amended. Appendix A contains the SOP for the MSCL.

2.6 Laboratory Testing Program

As previously discussed, one of the objectives of the LFRPD is to collect sufficient data to design the remediation project (removal of sediment with PCB concentrations greater than 1 ppm) and assemble specifications for remedial contractors to bid on the project. The design level data needs require many samples to be analyzed for PCBs to accurately determine the 1 ppm PCB dredge prism. However, the data needs to be collected at the lowest practical cost and in a timely manner.

2.6.1 PCB Analysis of Sediments

To achieve the data needs, extensive and unique methods have been developed to accurately characterize the extent of PCB impact. These methods include a Hybrizyme PCB immunoassay kit (IA kit) and a modified EPA Method 8082 known as the Fox River Method. These unique methods, followed by three sampling plans to determine the 1 ppm footprint, are described below.

The Hybrizyme Method provides a reliable method for screening sediment samples both above and below the 1 ppm dredge prism determinant concentration.

Hybrizyme Screening Method

As a more effective approach to reducing project costs and sample processing time, a screening method was developed with reliable results around the action level of 1.0 ppm PCBs. The IA kit is an immunoassay technique, as described in EPA Method 4020, that is appropriate for screening the Lower Fox River sediments.

The IA kit is a third-generation technique that differs from other immunoassay kits in that it relies on an Aroclor-specific development of fluorescence to determine the PCB concentration. The fluorescence endpoint helps to eliminate possible interferences and results in more accurate PCB concentrations than the traditional colorimetric endpoint.

The results of a method validation study to determine the comparability of the Hybrizyme Method and the Fox River Method are presented in the LFRPD QAPP Appendix C. The method validation study showed that the IA kit is useful for determining whether samples are greater than or less than 1 ppm. Preliminary results indicate that the Hybrizyme Method will confidently determine that a sample is less than 1 ppm if the IA kit is 0.5 ppm or less. The validation study also appears to show that a sample greater than 1 ppm can confidently be predicted when the IA kit is 2 ppm or greater. An SOP for conducting the IA kit is included in Appendix D of the QAPP.

Fox River PCB Method

The Lower Fox River sediments present sample matrix issues, which have resulted in low-biased concentration results. To minimize the matrix effect, a specialized extraction method has been developed by En Chem. The Fox River PCB Method is a modified EPA Method 8082, which has been determined to accurately determine PCB concentrations in Lower Fox River sediment.

The Fox River PCB Method requires the use of air-drying and homogenizing the sediment sample prior to soxhlet extraction. Cleanup techniques employed on the extracts may include open-column chromatography with Florisil, shaking with elemental mercury to remove sulfur, and the addition of sulfuric acid to remove contaminants that may interfere with Aroclor identification and quantitation. Analysis is done by gas chromatography with electron capture detection (GC-ECD) using external Aroclor standards. The limit of detection (LOD) achieved by En Chem is 0.022 mg/kg.

A laboratory SOP for the Fox River PCB Method is included in Appendix D of the QAPP.

Sampling Plan Approach

Three different approaches to determining the 1 ppm footprint have been evaluated. Each approach has been evaluated for concentration accuracy and completeness, cost efficiency, and the ability to meet the project schedule. The approaches and a brief description of each are:

- Sampling Plan A consists of analyzing all core sections, except the top 10-centimenter section of each core, with the IA kit as a screening method and confirming select sample results with the Fox River PCB Method. Core section samples would be collected in 10-centimenter intervals over the entire core length. This plan provides complete core section analysis in a timely manner with one laboratory generating the data for ease of comparison.

The Fox River PCB Method will be performed as a confirmatory method on select samples as indicated in the following:

- If the total PCB concentration of a sample or the duplicate/co-located sample exceeds the screening method Reporting Limit (RL) of 0.5 ppm and is less than the upper screening level (USL) of 2 ppm, the sample will be selected for confirmatory analysis by the Fox River PCB Method

- Up to 5 percent of the samples that do not exceed the screening method RL of 0.5 ppm will be analyzed by the Fox River PCB Method

- Up to 5 percent of the samples that exceed the screening method USL of 2 ppm will be analyzed by the Fox River PCB Method

- Sampling Plan B consists of analyzing core sections from the bottom up using the Fox River PCB Method. For this option, core section samples would be collected in 10 cm intervals and analyzed in stages, dependent on the previous sample results. Sample analysis would continue until the analytical results indicate concentrations greater than 1 ppm, which would define the depth of sediment removal. While this plan may be cost effective and involves only one laboratory, it does not provide analytical data for the entire core and would likely not meet the project schedule recognizing that repeated sample submittals to the laboratory based on previous results will be required. Further, since some of the physical parameters must be measured within the 1 ppm delineation, it will not be known for some time which core sections should be submitted for analysis, thus creating a sample control/tracking complexity which can easily result in errors.

- Sampling Plan C consists of analyzing all of the core sections using the Fox River PCB Method. Core section samples would be collected in 10 cm intervals over the entire core length. This plan provides accurate and complete sample results; however, the analytical program will not be cost effective or meet the project schedule. In addition, a minimum of two laboratories would be required to handle the sample quantities, which may result in data comparability issues.

Based on the results of the Hybrizyme Method validation study provided in Appendix B, Sampling Plan A will be used to delineate the 1 ppm PCB dredge prism in OUs 3 and 4.

2.6.2 Additional Chemical Analysis of Sediments

Table 2-4 summarizes the sediment chemical analyses to be preformed during the LFRPD. Samples will be collected, handled, and analyzed in accordance with the methods described in the LFRPD QAPP Section 2.3.

Total Organic Carbon

Select sediment samples will also be analyzed by En Chem Laboratories for total organic carbon (TOC) by Wet Chem Method-9 (WCM-9) or WCM-18. Sample locations will be selected in areas of the 1 ppm PCB dredge prism which may be appropriate for capping as re-defined by the Geophysical Survey activities described in Section 2.2 of this SAP. The TOC results will be used to evaluate PCB bioavailability in these areas.

2.6.3 Chemical Analysis of Pore Water and Leachate for Potential Capping Areas

Following delineation of areas appropriate for capping based on the physical criteria presented in the Feasibility Study and RODs, approximately five sediment samples will be collected and composited from each OU for use in pore water analysis. Pore water will be collected from each sediment sample by centrifuging and decanting the free water. In addition, sequential batch leach test (SBLT) will be performed to generate data that will be used when simulating potential chemical flux through a cap.

PCBs

The resulting pore water will be analyzed by En Chem Laboratories for PCBs as Aroclors by Method SVOA-6 and SVOA-52. The results will be used to evaluate PCB bioavailability and areas of the River that may potentially be capped.

TOC

The TOC and dissolved organic carbon (DOC) of the pore water will also be analyzed by En Chem Laboratories to assess areas of the River that may potentially be capped.

2.6.4 Chemical Analysis of Leachate for Design of Disposal Facility

The solids from the testing of dewatering processes will be analyzed to simulate the leaching characteristics in a landfill setting.

Analytical Resources, Inc. (ARI) will perform a column leach test of solids generated by the treatability work described below in Section 2.7. The resulting leachate will be sent to En Chem or Axys Laboratories for further analysis as described below.

The concentrations of these parameters will be compared with NR 140 standards (for the sake of determining potential liner design modifications from NR 500).

PCB Congeners

Axys Laboratories will analyze the leachate derived from the column leaching test for PCBs as congeners per Method MLA-007 in accordance with the QAPP.

Metals

Select metals including: iron, zinc, manganese, lead, cadmium, and mercury will be analyzed by En Chem Laboratories in accordance with the methods provided in Table 2 of the QAPP.

Volatile Organic Compounds

The leachate will be analyzed for volatile organic compounds (VOCs) by En Chem Laboratories by Method G3-VOA-1 in accordance with Table 2 of the QAPP.

Polycyclic Aromatic Hydrocarbons

The leachate will be analyzed for polycyclic aromatic hydrocarbons (PAHs) by En Chem Laboratories by Method SVO-1, SVO-2, and SVOA37R in accordance with Table 2 of the QAPP.

Additional Parameters

The leachate will be also be analyzed for additional parameters including: hardness, conductivity, pH, biological oxygen demand (BOD), chemical oxygen demand (COD), sulfate, chloride, and ammonia by En Chem Laboratories in accordance with the methods provided in Table 2 of the QAPP.

2.7 Treatability Testing

This section describes a set of interrelated treatability tests that is needed to provide basic process design information for the thickening and dewatering of dredge slurry and the treatment of wastewater generated during these operations. Characterization of the solid residuals that result from the dewatering process also falls in to this category. These tests will be conducted on a focused set of samples specifically selected on the basis of sediment grain size distribution. For grouping and sequencing purposes, the inter-related testing is organized into a series of protocols, the sequence of which is indicated on Figure 2-4.

The individual tests within each protocol provide data necessary for design of specific treatment processes or disposal facilities. These protocols and their component tests correspond to the following actual full-scale operations:

- **Protocol A:** This protocol is written to provide a method for selecting a set of sediment samples for treatability purposes that represents the range of in-place materials, using grain size distribution as the selection criteria. It is applicable to both OUs.

- **Protocol B:** This protocol simulates the handling and processing of sediment in slurry form. For samples that will be tested for mechanical dewatering, the slurry is first processed to remove coarse material (sand). Otherwise, the simulated slurry is thickened, which represents either a passive process in a basin or a mechanical process in a tank.

- **Protocol C:** This protocol tests different methods for the mechanical dewatering of thickened slurry. The resulting filter cake is then tested for physical and chemical characteristics needed for the design of a land disposal facility.

- **Protocol D:** This protocol is similar to Protocol C, except that it does not include the mechanical dewatering step. It tests the physical and chemical characteristics of sediment that has been passively dewatered and dried in a basin, and destined for disposal in a landfill.

- **Protocol E:** This protocol tests the clarification characteristics of a simulated wastewater that would be generated from several points in a full-scale system. These include the supernatant from a passive dewatering basin (represented by Protocol B), the supernatant from a mechanical thickener (Protocol B) or the filtrate from a dewatering press (Protocol C).

The protocols will be used in different sequences depending on which set of full-scale processes is to be simulated and tested. In some cases, like the settling test in Protocol B, the test actually provides data for two processes: the thickening that occurs in either a settling basin or a mechanical thickener.

The RODs have identified, in general, the processes that will be used at both OUs. Therefore, the treatability work will vary slightly according to which

OU is being evaluated. For each OU, the sequence of protocols that will be used is as follows:

OU	Major Processes Selected in the Proposed Plan or Possible Substitutions	Treatability Protocols Used
3 and 4 (Proposed Plan)	Hydraulic dredging, passive dewatering, wastewater treatment, and landfill disposal	A, B, D, E
3 and 4 (Possible Alternative to Proposed Plan)	Hydraulic (or hybrid) dredging, mechanical thickening, dewatering, wastewater treatment, and landfill disposal	A, B, C, E

As seen in this table, there are a total of four treatability sequences that are generated: two each for OUs 3 and 4. As will be described below, approximately five samples plus a blind duplicate will be generated from each OU for testing. Therefore, a total of up to 24 samples will be subjected to the initial protocols of the treatability testing process. However, for efficiency and cost savings, the number of samples that are carried forward into the later protocols can be reduced. This is illustrated in Table 2-5 (Number of Samples Processed Under Each Treatability Sequence).

Each individual treatability protocol and its component tests is described in the subsections below. Other physical and geotechnical testing is also described in Sections 2.8 through 2.10.

2.7.1 Protocol A: Sediment Classification for Treatability Testing for OUs 3 and 4

Approximately 30 cores will be collected in duplicate from areas of both OUs 3 and 4, which will encompass sediment grain size distribution extremes (as characterized in previous investigations). The cores will be collected and tested at the beginning of the first phase of sediment sampling for each OU so the actual treatability design work will be performed concurrently with the PCB delineation sampling.

Regardless of whether dredged material will be mechanically or passively dewatered and which OU the sediment comes from, the initial step of each process is to screen and classify sediment with respect to grain size distribution and Atterberg limits as described in Table 2-6 (Protocol A). Screening results will be used to select five sediment types (based on percent sand resulting from grain size analysis) to perform the treatability testing on.

2.7.2 Treatability Sequence using Mechanical Dewatering for OU 3 and OU 4

Up to five samples, plus a duplicate from both OU 3 and 4, will be subject to treatability testing for the mechanical dewatering process after they have been subjected to Protocol A. Protocols B, C, and E will be followed for these samples. This is summarized in Table 2-5 (Number of Samples Processed Under Each Treatability Sequence).

Protocol B

Protocol B simulates testing slurry pre-processing and thickening prior to dewatering and is described in Table 2-7. Simulated dredge slurry of approximately 8 percent solids will be created. This slurry will be screened for sand if it is greater than 10 percent sand. The resultant slurry will be subjected to a column settling test. The thickened sediment resulting from the column settling test will be subjected to Protocol C. The supernatant from the column settling test will be subjected to Protocol E.

Protocol C

Protocol C specifies that at least two common dewatering processes be tested: belt presses and filter presses. In both cases, it is recommended that this testing be performed using equipment vendors' proprietary methods. The equipment requirements, chemical demand, and labor effort for the full-scale Lower Fox River project will be substantial. The demonstration projects and preliminary evaluations completed to date indicate that dewatering can be successfully implemented, and that both belt presses and filter presses are viable processes. The development of a final design and a realistic project budget now requires that actual equipment be selected for the full-scale project.

The objection to using vendor treatability methods is that the data is not fully "portable." For example, in some instances, an owner may be locked in to a proprietary piece of equipment and competitiveness is reduced. For the Lower Fox River, however, these potential drawbacks are mitigated as follows:

- The testing of two competing process options – belt presses and filter presses – retains a degree of competitiveness among suppliers.

- The dewatering component of the integrated dredging/dewatering project may only comprise 20 to 30 percent of the total project cost. At the point of final procurement, there will still be ample room for competitive proposals among a range of bidders.

- As part of an integrated project that has significant performance-based components, bidders would not necessarily be required to use either of the two processes tested. In this regard, the proprietary testing will merely provide the owner and WDNR with a higher degree of knowledge concerning the typical sizing and costs that are likely to be incurred. This in turn will serve as a basis for evaluation of potentially disparate proposals by bidders, and provide a check against what may be an underestimate of the equipment necessary to accomplish the project.

While solids dewatering is a well-advanced technology, there is not a large body of experience with the dewatering of sediment at the scale required for the Lower Fox River project. At least two competing suppliers have been starting to develop an expertise in this area. Andritz, Inc. is a major supplier of belt presses and has performed some initial bench-scale work on Lower Fox River samples. U.S. Filter is a diversified, international supplier of water and wastewater equipment, and has been involved in the evaluation of filter presses for the New Bedford Harbor Superfund site. After balancing the drawbacks and benefits described above, it is recommended that these two suppliers be used for the bench-scale dewatering tests on Lower Fox River samples.

The dewatered solids resulting from the vendors' proprietary treatment methods will be subjected to the following physical property testing:

- Percent solids
- Density
- Atterberg limits
- Compaction characteristics
- Consolidation
- Unconsolidated-undrained triaxial compression test
- Consolidated-undrained triaxial compression test

See Table 2-8 (Protocol C) for specific ASTM methods.

Protocol E

Wastewater will be generated both from the slurry thickening and passive dewatering processes as a supernatant. It will also be generated from a mechanical dewatering operation as a filtrate. It is expected that each of these wastewater streams will require clarification, filtration, and granular-activated carbon (GAC) polishing prior to discharge.

The filtration and GAC polishing processes are basic operations using well-advanced technologies. No treatability work is required for these processes.

The clarification of the two primary wastewater streams will be sensitive to the type and rate of chemical addition. Therefore, a bench-scale jar testing program, with subsequent column settling tests, will be implemented. This protocol is summarized in Table 2-10.

One of the recommendations from the demonstration project at SMU 56/57 was that the supernatant and filtrate should not be commingled and should be treated separately. The reason for this recommendation is not clear, but may have been due to the heavy doses of lime used as a filter aid. In any event, the protocol described in Table 2-10 includes the separate testing of these two streams. Based on the results and engineering judgment, it may later be determined that combined treatment will be effective.

2.7.3 Treatability Sequence Using Passive Dewatering for OU 3 and OU 4

Up to five samples each from OUs 3 and 4 will be subject to treatability testing for the passive dewatering process after they have been subjected to Protocol A. Protocols B, D, and E will be followed for these samples. This is summarized in Table 2-5 (Number of Samples Processed Under Each Treatability Sequence).

Protocol B

Protocol B involves testing slurry pre-processing and thickening prior to dewatering and is described in Table 2-7. A simulated dredge slurry of approximately 8 percent solids will be created. The slurry will be subjected to a column settling test. The thickened sediment resulting from the column settling test will be subjected to Protocol D. The supernatant from the column settling test will be subjected to Protocol E.

Protocol D

Protocol D involves testing the characteristics of passively dewatered solids. The thickened slurry from Protocol B will be dewatered to simulate conditions expected during remediation. Percent solids will be measured to verify that the solids have reached 40 percent or greater. After drying, the solids will be subjected to a one-dimensional consolidation test (see Table 2-9 for ASTM method), or equivalent. The dried consolidated sediments will then be subjected to the following tests:

- Percent solids
- Density
- Atterberg limits
- Compaction characteristics
- Unconsolidated-undrained triaxial compression test
- Consolidated-undrained triaxial compression test

See Table 2-8 (Protocol C) for specific ASTM methods.

Protocol E

Wastewater will be generated from the passive dewatering processes as a supernatant. It is expected that this wastewater will require clarification, filtration, and GAC polishing prior to discharge.

The filtration and GAC polishing processes are basic operations using well-advanced technologies. No treatability work is required for these processes.

Clarification will be sensitive to the type and rate of chemical addition. Therefore, a bench-scale jar testing program, with subsequent column settling tests, will be implemented. The protocol is described more fully in Table 2-10.

2.8 Physical and Geotechnical Testing

For the cores taken from sample locations that are not subject to the focused treatability work described above, additional physical and geotechnical testing will be performed. The purposes of this work is to collect the raw data necessary for the following:

- More accurately calculating the mass of solids that is present within the expected dredge prism
- Determining the strength properties and chemical partitioning of the existing sediment bed within the footprints that are being evaluated for a possible *in-situ* cap, in the event that that remedy is found to be an acceptable response.

The program will consist of the following tests and frequency (also see Table 2-4):

Test	Frequency
All Core Locations in Each OU	
Density (ASTM D2937) Percent Solids (ASTM 2216, with results reported as solids, rather than water content) Specific Gravity (ASTM D854)	• 1 sample per every 2 feet of core (or fraction thereof in excess of 1 foot) • The density measurements may be obtained by the core logging methodology described in Section 2.4 • Requires undisturbed sample, collected using thin-wall tube method
Grain Size, with Hydrometer (ASTM D422) Atterberg Limits (ASTM D4318)	• Each core, interval taken from within major horizons, not to exceed two intervals per core (i.e., thin sand seams of a few inches thickness need not be characterized)
Only at Core Locations Where Capping is Being Evaluated	
Pore Water (by centrifugation)	• Five tests per OU, distributed across the OU based on the variability observed during the initial sediment screening and classification described above

Test	Frequency
SBLT (ARI Sequential Batch Procedure)	• Five composites per OU in areas to be capped based on the variability observed during the initial sediment screening and classification described above
Unconfined Compression (ASTM D2166 or equivalent)	• Up to 30 tests per OU, distributed across the OU based on the variability observed during the initial sediment screening and classification described above • Requires undisturbed samples, collected using thin-wall tube method
Consolidation Test (and/or Self-Weight Consolidation; ASTM D2435 or USACE equivalent)	• Five to ten per OU, distributed across the OU based on the variability observed during the initial sediment screening and classification described above
Field Vane Shear Test (ASTM STP 883)	• One per acre
In OU 3 and OU 4 Only (where vitrification may be considered)	
Mineralogy (x-ray fluorescence)	• Thirty to 40 samples per OU, randomly distributed, based on initial sediment screening and classification described above

2.9 Geotechnical Investigation at Potential Riverside Processing Sites

The implementation of the remedial action will require the construction of various infrastructures at one or more locations along each OU. These will consist of buildings, large tanks, process equipment, and support facilities (access roads, laydown areas, etc.).

Specific parcels have not been designated for this purpose. In OU 1, the Bergstrom Fill has been suggested as a likely candidate based on its location and other attributes. However, this is also an example of a site with potentially significant geotechnical limitations due to the historic filling with low-strength materials. Sites with comparatively poor subsurface conditions will require more substantial foundations to support the proposed facilities.

It is necessary to identify and secure access at specific parcels prior to final engineering. Once the parcels are selected, the geotechnical investigations will be performed to generate the soils data for design of building, tank, and equipment foundations. The investigations may consist of the following components:

- Drilling of test borings and performing standard penetration tests (ASTM D1586)
- Recording blow counts (N-values), soil classifications, water levels and other observations

- Collecting of undisturbed samples using thin-walled tubes (ASTM D1587)

- Performing strength and consolidation tests on the undisturbed samples

- Test pit excavating in locations where large, bulk fill is present, to determine the nature and variability of subsurface conditions

- Surveying the ground elevation and location of each boring and test pit using the coordinate system and survey monuments described in Section 2.1 of this SAP.

The number of test borings (and potential test pits) will depend on the conditions and the size of the parcel. The locations of the borings and test pits should be focused on the expected locations of new structures and equipment. The scoping of the investigation, and the interpretation of subsurface data, will be performed by a geotechnical engineer.

2.10 Decontamination Procedures and Disposal of Derived Investigative Waste

When practicable, disposable equipment will be used for sampling, homogenizing, and subsampling procedures (e.g., core liners, bowls, spoons, and aluminum pans). However, when equipment is reused (e.g., core catcher), decontamination steps will be followed to ensure samples are not cross-contaminated. The procedures for field decontamination of equipment includes the following:

- Remove solid particles from the equipment or material by brushing and then rinsing with available tap water

- Wash equipment with a brush and a phosphate-free detergent solution

- Rinse with tap water

- Rinse with acetone

- Rinse with distilled/deionized water

Unless the equipment is going to be used immediately, it will be wrapped in new aluminum foil (shiny side out) to keep it clean until needed. For large bulky equipment, new visqueen can be substituted for the aluminum foil.

Standard decontamination practices will be followed for coring equipment removed from the site. The sediment sampling subcontractor will provide a steam cleaner and a decontamination area will be established on the site for decontamination of the rig, vibrating head, and cores used for the borings. No oils, greases, or other petroleum-based products will be used on any down-hole equipment. Sampling equipment (including core samplers, sampling spatulas, etc.) will be cleaned using the methods listed above prior to the collection of each sample. Decontamination wash and rinsate will be containerized in drums and properly disposed of.

Derived investigative waste includes personal protective equipment (PPE), residual sediments, rinse water, and rinse solvents. PPE will be disposed of as a solid waste in plastic trash bags and put in dumpsters for disposal in a NR 500 licensed landfill.

Incidental sediment spillage on the sampling vessel will be washed overboard prior to vacating the station. Sediment residuals from the sampling facility will be containerized and disposed of with dredged materials removed during the implementation of the remedy, or a licensed NR 500 landfill as was previously done by WDNR during the 1995 characterization of OU 4. Leftover sample from the laboratories will be saved until data are validated. After data are validated, leftover samples will be containerized and disposed of with dredged materials removed during the implementation of the remedy, or a licensed NR 500 landfill.

Water rinsate will be disposed of in a sanitary sewer after receiving approval from the local sanitary operator, as was previously done by WDNR during the 1995 characterization of OU 4. Rinsate solvents, if any, will be containerized and properly disposed of through a properly licensed waste hauler.

2.11 Quality Assurance/Quality Control (QA/QC)

A QAPP has been developed to describe the personnel, procedures, and methods to ensure quality, accuracy, precision, representativeness, completeness, comparability, and sensitivity of laboratory- and field-generated data. The QAPP was designed such that data collected will meet the Region 5 EPA and the WDNR standards and provide adequate information to assess remedial alternatives for the Lower Fox River. The QAPP will be approved by the EPA and the WDNR.

The objectives of the Pre-Design Characterization Study are:

- Collection of sufficient data to design the remediation project (removal of sediment with PCB concentrations greater than 1 ppm)

- Assembly of specifications for remedial contractors to bid on the project

EPA analytical methodology and protocol will be used to review the completeness of the data generated, adherence to quality control (QC) requirements, and to evaluate data usability.

2.11.1 Field QA/QC Assessment

Quality assurance (QA) for Pre-Design Characterization activities is managed through the implementation of SOPs for instrument calibration, sample collection, preservation, and sample handling, packaging, and shipping. SOPs are included in Appendix D of the QAPP, Laboratory QA/QC Assessment.

Laboratory QA will be assessed through field duplicate samples, continuing calibration verifications, laboratory control samples, matrix spike/matrix spike duplicate samples, and adherence to laboratory SOPs as described in the QAPP. Laboratory SOPs are available upon request.

Field completeness shall have a goal of 90 percent for each media and analysis.

2.11.2 Field Audits

Inspection is a key component of the QA/QC program. Field sample collection, core and sample processing, as well as the analytical laboratories will be audited regularly. The physical and geotechnical analyses data are critical to the design of the project. Audits of the dedicated facility will be conducted prior to initiation of the analyses. Investigative field activities will be audited during sample collection and analysis to verify compliance with the QAPP and SAP.

3 Data Management

This section describes the process for the collection, organization, evaluation, and reporting of technical data to support the monitoring activities described in this document. The term technical data is used to refer to the field observations, laboratory analytical results, physical or geotechnical testing results, and validation data generated to interpret site conditions and characterize the performance of remedial actions.

In addition, this section describes the system used to make this data and the resulting work products available to personnel working on the project. The resulting work products are calculations, models, drawings, etc., that are derived from technical data and the written reports used to document the evaluations. Additional types of data, managerial data (e.g., audit reports, surveillance reports, storage records, project tracking records) are also maintained in the data management system.

NRT field technical staff members will manage raw data during field activities. Data such as depth measurements and water levels will be recorded on the appropriate field forms (located in Appendix E of the QAPP) or in a field book. During the course of the investigation, the RETEC data manager will periodically collect field and laboratory data to maintain a current summary of results. This will enable the RETEC data manager to identify any data gaps during the course of the project. Noted deficiencies in field QA/QC will be brought to the attention of the RETEC QA Manager.

Each laboratory's project managers will be responsible for laboratory data management. Analytical data reports generated by each laboratory will present all sample results, including all QA/QC samples. All data, including QA/QC results, will become part of the project files and will be maintained by the RETEC data manager. Upon laboratory report delivery, RETEC personnel under the supervision of the RETEC data manager will analyze laboratory data in accordance with accepted statistical methodologies, as appropriate.

3.1 Data Management Plan

The data management plan should indicate, via a flow chart, each data transfer and reduction step in processing data. These flow charts will be used to trace a data set from stored data to the final deliverable. QC procedures should include random checks of transfer accuracy and completeness. Procedures should also address the reliability of calculations and the overall correctness of the data reduction. The algorithms and procedures used for data reduction should be verified against a known problem set.

Information that is stored in the FRDB will be audited periodically to verify record integrity, retrievability, and security. Periodic record audits should also be conducted to verify that the number of entries made equals the number of records logged and that data output correctly corresponds to data input.

Prior to "mixing" data sets or adding to an existing data set, the comparability of the data will be verified and documented. For this purpose, comparability should be based on the type of data, the comparability of the methods used to generate the data, the assessed quality of the data, and compatibility of the electronic files.

Approved data management procedures will be implemented to ensure the integrity of stored project data in terms of accuracy, completeness, and accountability. Data management procedures and controls shall provide appropriate security against unauthorized retrieval or modification of the information, whether intentional or unintentional.

3.2 Environmental Information Management System (EIMS) Data Management

Technical data, including field observations, laboratory analytical results, and analytical data validation, lends itself to storage in a relational database structure in order to make the data queryable. The Agencies (WDNR and EPA) will manage this data using EQuIS®, a third-party database application that is becoming a standard for the management of environmental data (see www.earthsoft.com). Historical analytical data stored in the FRDB, the current data warehouse for Lower Fox River and Green Bay analytical data, will be available in EQuIS® format. In addition, requiring that data be provided in an EQuIS®-compatible format will facilitate importing future data (see http://www.epa.gov/region5superfund/edman/download/EDD%20V1_05.pdf).

The RETEC database administrator will be responsible for uploading electronic sample collection form data into the EQuIS® database. The RETEC database administrator will also be responsible for archiving the EIMS data in an EQuIS®-compatible format so that the data can be accessed by WDNR and USEPA in the event the EIMS is not available.

Data received from analytical labs in electronic data deliverable (EDD) format (QAPP Appendix F), received as EQuIS®-compatible text files from laboratories, will be checked for completeness by comparing them to the sample collection form data before appending them directly into the EQuIS® database, where the records will be flagged as "Unvalidated." At this point, the analytical data will be available for search and download only by users of the EIMS who have been granted permission to see unvalidated data. Data will be promptly exported and transmitted to a data validator, where the appropriate quality checks are completed. Finally, the database administrator will upload updated results including Validation Qualifiers received from the data validators, and will make these results available to the general EIMS user community.

In addition to analytical data, the EQuIS® database will be used to organize field observation data, including field parameter results. This data will be transcribed by field personnel into electronic files, where they will be uploaded into EQuIS® with the assistance of the database administrator. This data will then be available for data evaluation though EQuIS® exports, as described below.

3.3 Data Reduction and Review

Procedures for ensuring the correctness of the data reduction process are discussed in this section. Both field and laboratory generated data will be reduced manually on calculation sheets or by computer on formatted printouts. Responsibilities for the data reduction process are delegated as follows:

- Technical personnel will document and review their own work and are responsible for the correctness of the work

- Calculations will receive a method and calculation check by a secondary reviewer prior to reporting (peer review)

- The Chemistry QA Officer will be responsible for ensuring that data reduction is performed according to protocols discussed in the QAPP

3.3.1 In-Laboratory Data Reduction and Review

Data generated by the laboratory will be reviewed prior to data release. The laboratory will perform three levels of data review:

- Analytical level
- Data section level
- Final quality review

Laboratory review processes are documented in the Quality Assurance Manuals (Appendices A, B). The laboratory will insert statements in a comment field to qualify data results. Technical data will be reported according to the established QA/QC procedures in Section 1.8.4. Special consideration will be given to replicate measurements, identification of outlier values, and results reported below detection limits, as discussed below.

Outliers or numbers that lie outside of the expected range of values may occur. Outlier values may be the result of an occurrence such as a spill, inconsistent sampling or analytical chemistry methodology, errors in transcription of data values, or actual but extreme concentration measurements. Outlier values will be corrected if the problem can be documented. Documentation and validation of the cause of outliers must accompany any attempt to correct or delete data values. Actual but extreme values will not be altered. Outlier values will be identified, but will not be omitted from raw data tables.

Analytical values determined to be at or below the RL but above the method detection limit (MDL) will be reported numerically with a "J" qualifier to indicate that the value is estimated because it lies between the MDL and RL (or LOD and limit of quantification [LOQ]) where quantitation is less precise than above the RL (or LOQ). Values below the MDL or LOD will be reported as "<" XX, or XX "U" where XX is the numerical value for the MDL or LOD. Abbreviations such as "BDL" (below detection limit) or symbols will not be substituted for the numerical detection limit when reported values are below the detection limit.

When computing statistics where one or more of the data values are below the detection limits, several approaches are possible (e.g., setting the sample value equal to zero, one-half the detection limit, or the detection limit). The statistical method used will determine what approach is specified. Regardless of the approach used, the respective assumptions will be indicated as a footnote in tables reporting statistical results.

3.4 Data Evaluation

Data evaluation involves the processing of technical and literature data to assess site conditions and to characterize the performance of remedial actions. Data evaluation will be conducted using a combination of database exports, industry standard analysis software, and user analysis.

3.5 Tabular Data

Presentation tables will consist of two types, raw data tables and reduced data tables. Raw data tables may not illustrate trends or patterns, but are valuable for validation and auditing purposes. Reduced data tables may present data as a function of depth, location, or matrix. Reduced tables also include tables derived from raw data tables by additional calculations or other manipulations, such as counts, averages, maximums, and 95 percent upper confidence limits (UCLs).

Raw data tables will be primarily created using the EQuIS® CrossTab Report Writer application, a general report writer designed to work with EQuIS®

projects. This reporting tool is not a hard-coded report generator limited to a few "canned" report formats. Instead, the EQuIS® CrossTab Report Writer application is a highly configurable and customizable general purpose X-Tab report generator. This application will be used to export analytical data from the EIMS technical database to Microsoft® Excel or text file format. Export decisions, such as fields selected, sort orders, and filter criteria, are saved, thereby ensuring the reproducibility of the exports. Whenever a data export is completed to make a raw data table, the date and time of the export as well as a readable version of the Structured Query Language (SQL) statement will be included with the export file.

Reduced data tables will generally be created using spreadsheet calculations. These files will be printed out in both equation form and calculation form. An engineer or scientist of a professional level equal to or higher than that of the originator will review all equations. The secondary reviewer will sign and date the calculation sheet immediately below the originator. Both the originator and secondary reviewer are responsible for the correctness of the calculations. The calculation sheet will document the following (at a minimum):

- Project title and project number
- Initials and date of originator
- Initials and date of secondary reviewer
- Basis for calculation
- Assumptions made or assumptions inherent in the calculation
- Complete reference for each source of input data
- Methods used for calculation
- Results of calculation

3.6 Maps and Drawings

The distribution of chemicals, if present, may be represented by superimposing contaminant concentrations over a map of the investigation area. Distributions may be shown by listing individual measurements or by contour plot of the contaminant concentrations or other parameters (isopleth map). Regardless of the method used, all maps will include a title, scale, legend, and north arrow. The date, project number, and operator's name will also be included. Base maps used will be properly referenced. The contour interval will be indicated and contour lines will be labeled.

The primary tool to be used for the creation of maps and drawings will be ArcView, a product offered by ESRI. Data presented in these maps will include the results of raw data exports and data reduction results. Additionally, existing GIS layers available from previous work done on the Lower Fox River and from regional government agencies may be included on these maps. All GIS layers used in the creation of maps and drawings will be available as files in the Document Management module of the EIMS.

3.7 Hand Calculations

At times, data evaluation may require the use of hand calculations. They will be recorded on calculation sheets, written legibly and in a logical progression. An engineer or scientist of a professional level equal to or higher than that of the originator will review the calculations. The secondary reviewer will sign and date the calculation sheet immediately below the originator. Both the originator and secondary reviewer are responsible for the correctness of the calculations. The calculation sheet will document the following (at a minimum):

- Project title and project number
- Initials and date of originator
- Initials and date of secondary reviewer
- Basis for calculation
- Assumptions made or assumptions inherent in the calculation
- Complete reference for each source of input data
- Methods used for calculation
- Results of calculation

4 Reports

4.1 Bi-Weekly Project Status Reports

Bi-weekly project status reports will be prepared for submittal to the WDNR Project Manager. The status reports will summarize the following:

- Field and laboratory activities that were completed in the previous 2 weeks
- Field and laboratory activities scheduled for completion the next 2 weeks
- Address the project schedule
- Document correspondence with agencies and Site visitors

4.2 Weekly Field Progress Reports

A weekly field progress report will be submitted to summarize the following:

- Field investigation activities conducted the week prior
- Field investigation activities scheduled for the completion the next week
- Copies of chain of custody receipts for samples submitted to the analytical laboratory
- A Sample Control Log for samples/cores submitted for analysis of geotechnical or engineering properties
- A variance log

The variance log will document investigation activities that were inconsistent with the Work Plan, QAPP, and/or the SAP with a brief description of the variance and reason for the variance. The variance log will be submitted to the Project Quality Assurance Manager to assess how variances may affect the quality of the data to meet the objectives of the project and the need for additional field investigation activities.

4.3 Weekly Laboratory Progress Reports

A weekly laboratory progress report will be submitted to summarize the following:

- Samples received by the laboratory (analytical and geotechnical) the week prior
- Samples processed by the laboratory (analytical and geotechnical) the week prior
- Deviations from the laboratory SOPs
- Summaries of any samples which were analyzed outside of the holding time, or had to be reanalyzed due to interferences, poor recoveries, poor ongoing calibration results, or any other laboratory difficulties
- Analytical and geotechnical sample results, if available (final results only)

4.4 Monthly Progress Reports

A monthly progress report will be submitted with each invoice that will summarize the following:

- Project milestones and activities (field and laboratory) that have been completed over the invoiced period of time
- Project milestones and activities (field and laboratory) that will be completed over the next month
- A summary of all variances and QA/QC deficiencies
- A summary of the project schedule with a revised schedule provided, as necessary
- A budget summary including billed-to-date, current invoice, and project budget remaining

4.5 Annual Reports

Annual reports will be prepared to summarize the following:

- A summary of the methods and techniques used to collect the sediment samples

- Project milestones and activities (field and laboratory) that have been completed
- Laboratory methods used to analyze sediment samples
- A summary of all variances, QA/QC audits, and QA/QC deficiencies
- Final analytical data will be presented in tabular and graphical format, as appropriate, such that sample results exceeding 1 ppm for PCBs are highlighted
- River cross sections, topographic and geophysical mapping (including features which may restrict capping alternatives), as appropriate
- Data validation reports, if available

4.6 Basis of Design Report

The final report for the project will be a BODR. The purpose of this report will be to summarize the results of the pre-design sampling and treatability program in such a way as to document final decisions on technology process option selection and to support the remedial design process. The content of the BODR will be used to finalize the engineering design of the remedy, to size process equipment and facilities, and then to prepare final construction plans and specifications suitable for a contractor bidding process.

The BODR will include the following elements:

Section	Content
Extent of impacts	• Tabular summary of PCB results • Contour map of sediment bed elevation, including x,y footprint of material exceeding the 1 ppm RAL • Contour map of the bottom of the 1 ppm RAL • Calculation of volume of material exceeding the 1 ppm RAL
Site conditions	• Description of existing conditions that will affect the construction of the remedy, such as utilities and other subsurface obstructions. (Note that this section will be based on the interpretation of the sub-bottom and sidescan imagery generated during the site mapping tasks.)

Section	Content
Treatability – solids Protocol A: Sediment screening and classification	• Summary of the classification of sediments by grain size and other physical properties.
Protocol B: Slurry pre-processing and thickening	• Summary of slurry preparation, solids measurements and results of column settling tests. • Description of test results in the context of basin or thickener sizing.
Protocol C: Mechanical dewatering and residuals characterization	• Description of dewatering test results and the scale-up considerations for full-scale equipment sizing. Includes a discussion of the use and rate of addition of chemical conditioners. • Description of the physical and strength testing of the dewatered cake and how the results affect design and operation of a monofill for disposal. • Summary of leach testing results and their impact on design of a monofill liner.
Protocol D: Characterization of passively-dewatered residuals	• Description of the physical and strength testing of the dewatered sediment and how the results would reflect long-term settlement in an NR500 monofill. Include consideration for cover design and stability. • Summary of leach testing results and their impact on design of a monofill liner.
Treatability– wastewater (Protocol E)	• Description of jar testing and recommended chemical additive and dosage for full-scale wastewater clarification. • Interpretation of column settling test results and implications on sizing/selection of a full-scale clarifier.
Testing to support in-situ capping	• Description of the physical and pore-water testing results (Section 2.8) and how they would support the design of an in-situ cap.
Design concepts	• Description of recommended capping, removal, dewatering, wastewater treatment, and/or disposal processes (for each OU) • Process Flow Diagram and updated mass balance (for each OU) • Facilities locator plan (drawing), showing the proposed locations of staging, processing and disposal facilities necessary to implement the final remedy. Include transportation routes and/or intermediate materials handling steps. (Note: Geotechnical data from specific riverside parcels (Section 2.9) would be included here.)

Section	Content
List of drawings and specifications	• A list of all construction drawings and specification sections that will be developed during the final design process.
Permits	• A list of all local, state and federal permits required to implement the remedy. • Include approvals or access agreements necessary to construct and operate all remediation facilities.
Cost estimate	• An updated construction cost estimate based on the design concepts described herein. (Note: In USACE terms, this would be a pre-design "current working estimate (CWE)". In Superfund terms, it would be a post- FS estimate, but not yet an estimate based on a final design. As such, it would typically have an uncertainly level somewhere between +50%/-30% and +15%/-10%.
Schedule	• GANTT chart showing major tasks required to implement the project, including final design, permits and approvals, procurement and construction

5 Preliminary Project Schedule, Logistics, and Budget

Figure 5-1 shows an initial project schedule that assumes LFRPD work will start in OU 1 and will proceed downstream to OU 3 and finally to OU 4. This initial schedule assumes a sequential process that includes the completion of the SAP and QAPP before Notice to Proceed with any sample collection is given. Under this assumption this schedule illustrates that fieldwork in OU 1 may be completed before the end of this construction season.

The sequential nature of the SAP/QAPP approval process is but one assumption made in generating this initial project schedule. Each assumption can be modified and allowances made to individual elements that can result in schedule compression or delay. For instance, this schedule is based on a single sampling crew collecting 12 cores a day, 5 days a week. Multiple crews could be used to compress the schedule if so desired.

However, many of these tasks are interrelated and modifying one may result in necessary adjustments to others. In the single sample crew example, the assumption at present is that about 132 individual core segments would be produced per day (12 cores at 11 10-cm sections per core) and would be screened using the IA kit. En Chem's current capacity to run the IA screen is 60 samples per day which suggests that sample production would out pace the testing. Alternatively, En Chem can increase capacity to 120 screens per day by adding a second analyst, thus keeping pace with the sampling activity.

Another set of assumptions, which could be highly variable, are those associated with availability and mobilization of subcontractors. Given lack of clear notice to proceed, contractors we have talked to about implementing specific portions of this work have not been as responsive to our request as they would be if there were greater certainty about them performing the work.

Finally, having to redefine the physical boundaries of the soft sediment area to characterize also contributes a significant amount of uncertainty to both the scope and schedule of this project. The existing bed maps of physical properties are useful, to an extent, to assist the planning effort. But given the range of uncertainty associated with those data and the data manipulations over time, finer resolution of the scope and schedule are not possible.

Given the uncertainties and assumptions discussed above, a preliminary project budget is presented in Table 5-1. This preliminary budget is presented as a range since several components will not be adequately defined until some initial data collection activities have been completed.

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(http://www.dnr.state.wi.us/org/water/wm/lowerfox/index.html)

Tables

Table 2-1
Bathymetric Survey Specifications

Survey Classification	Special Order
Survey Equipment	• Phase 1: multiple-transducer sweep system, with ROSS 200-kHz single-frequency transducers • Phase 2: areas of extreme relief – multi-beam swath system, with RESON 455-kHz SeaBat 8125 transducer
Coverage	Phase 1: • Full coverage, entire length and width of each OU • 40-foot line spacing, longitudinal to flow • Cross lines at 100-foot spacing, perpendicular to flow Phase 2: • Full coverage over site-specific features
Equivalent Target Map Scale	1 inch = 50 feet (**Note:** The mapping will also be used at various smaller scales for different purposes on the project, but the accuracy of the bathymetric survey shall be based on a map scale no smaller than 1 inch = 50 feet.)
Feature Horizontal Location Tolerance	3 feet
Horizontal Control Survey Type	Third order, Class I
Resultant Elevation/Depth Accuracy	0.25 foot
Vertical Control Survey Type	Third order
Map Contour Interval	0.5 foot
Coordinate System	WTM 83
Vertical Datum	NAVD 88
Unit of Measure	U.S. survey foot
Output Electronic Format	Compatible with ArcGIS and AutoCAD
Output Hard Copy Format	ANSI D-size sheets (22 × 34 inches) (to allow half-scale plotting directly to 11 × 17 inches when needed)

Table 2-2
Side-Scan Sonar Survey Specifications

Survey Classification	Special Order
Survey Equipment	• Phase 1: Marine Sonics 600-kHz single-frequency side-scan sonar transducer • Phase 2: areas of concern – Marine Sonics 1,200-kHz single-frequency side-scan sonar transducer
Coverage	Phase 1: • Full coverage, entire length and width of each OU • Uniform elevation line tracts, longitudinal to flow Phase 2: • Full coverage over site-specific areas of concern
Equivalent Target Map Scale	1 inch = 50 feet (**Note:** The mapping will also be used at various smaller scales for different purposes on the project, but the accuracy of the side-scan sonar survey shall be based on a map scale no smaller than 1 inch = 50 feet.)
Feature Horizontal Location Tolerance	3 feet
Horizontal Control Survey Type	Third order, Class I
Resultant Range Resolution	Phase 1 (600 kHz): 0.32 foot at 165-foot range Phase 2 (1,200 kHz): 0.13 foot at 65-foot range
Coordinate System	WTM 83
Vertical Datum	NAVD 88
Unit of Measure	U.S. survey foot
Output Electronic Format	Compatible with ArcGIS and AutoCAD
Output Hard Copy Format	ANSI D-size sheets (22 × 34 inches)

Table 2-3
Sub-Bottom Profiling Specifications

Survey Classification	Special Order
Survey Equipment	EdgeTech multi-frequency chirp sub-bottom profiler, SB-216S, scanning between 2 and 16 kHz
Coverage	Full coverage, entire length and width of each OU (Same survey lines as side-scan sonar survey)
Feature Horizontal Location Tolerance	3 feet
Horizontal Control Survey Type	Third order, Class I
Resultant Elevation/Depth Accuracy	0.30 foot
Vertical Control Survey Type	Third order
Coordinate System	WTM 83
Vertical Datum	NAVD 88
Unit of Measure	U.S. survey foot
Output Electronic Format	JPEG
Output Hard Copy Format	None

Table 2-4
Analytical Parameters, Methods, Laboratory, and Estimated Sample Quantity for LFRPD Study

Sample Type	Analytical Parameter	Laboratory	Prep/Analysis Methods	OU 3 Number of Cores (or Formulated Sample for Treatability Work)	Typical Number of Sample (Intervals) per Core	OU 3 Field Samples	OU 3 Co-located Field Samples	OU 3 MS/MSD	OU 3 Lab Blanks	OU 3 Lab Duplicates	OU 3 LCS	OU 3 Total
Sediment (Section 2.3) – Chemicals												
	PCBs as Aroclors screen	En Chem	Hybrizyme	950	12	11,400	570	570	570	570	570	14,250
	TOC	En Chem	WCM-9 and WCM-18	20	6	120	6	6	6	0	0	138
	PCBs as Aroclors	En Chem	SVO-57, 26, 27/SVO-77	950	6	3,800	190	190	190	0	190	4,560
	% solids	En Chem	LAB-16	950	6	3,800	190	190	0	190	0	4,370
	% solids (air-dried sample)	En Chem	SVO-77	950	12	11,400	570	570	0	570	0	13,110
Sediment (Section 2.8) – Physical and Geotechnical, All Locations in Each OU												
	Density	CQM	ASTM D2937	950	0.15	143	7	0	0	0	0	150
	% solids	CQM	ASTM D2216	950	3	2,850	143	0	0	0	0	2,993
	specific gravity	CQM	ASTM D854	950	0.15	143	7	0	0	0	0	150
	grain size (with hydrometer)	CQM	ASTM D422	950	2	1,900	95	0	0	0	0	1,995
	Atterberg limits	CQM	ASTM D4318	950	2	1,900	95	0	0	0	0	1,995
Sediment (Section 2.8) – Physical and Geotechnical, Only Where Capping is Being Considered												
	Triaxial compression	SET	ASTM D2850 and/or ASTM D4767 (requires undisturbed sample)	10–20	1	20	0	0	0	0	0	20
	SBLT	ARI	USACE D-94-1/Appendix D	4–5	1	5	0	0	0	0	0	5
Leachate from SBLT Test on Sediment (Section 2.8)												
	DOC	En Chem	WCM-2 and WCM-18	4–5	1	5	0	0	0	1	0	6
	TOC	En Chem	WCM-2 and WCM-18	4–5	1	5	0	0	0	1	0	6
	PCB as Aroclors	En Chem	SVO-8/SVO-77	4–5		5	0	0	0	1	0	6
Sediment												
	GEOTEK MSCL	NRT	TAMU SOP	950	1	950	48	0	0	48	0	1,235
	mineralogy by XRF	The Mineral Lab	XRF	40	1	40					0	40

Table 2-4
Analytical Parameters, Methods, Laboratory, and Estimated Sample Quantity for LFRPD Study

Sample Type	Analytical Parameter	Laboratory	Prep/Analysis Methods	OU 4 Number of Cores (or Formulated Sample for Treatability Work)	Typical Number of Sample (Intervals) per Core	OU 4 Field Samples	OU 4 Co-located Field Samples	OU 4 MS/MSD	OU 4 Lab Blanks	OU 4 Lab Duplicates	OU 4 LCS	OU 4 Total
Sediment (Section 2.3) – Chemicals												
	PCBs as Aroclors screen	En Chem	Hybrizyme	1,466	12	17,592	880	880	880	880	880	21,992
	TOC	En Chem	WCM-9 and WCM-18	20	6	120	6	6	6	0	0	138
	PCBs as Aroclors	En Chem	SVO-57, 26, 27/SVO-77	1,466	6	5,864	293	293	293	0	293	7,036
	% solids	En Chem	LAB-16	1,466	6	5,864	293	293	0	293		6,743
	% solids (air-dried sample)	En Chem	SVO-77	1,466	12	17,592	880	880	0	880	880	21,112
Sediment (Section 2.8) – Physical and Geotechnical, All Locations in Each OU												
	Density	CQM	ASTM D2937	1,466	0.15	239	11	0	0	0	0	231
	% solids	CQM	ASTM D2216	1,466	3	4,782	220	0	0	0	0	4,618
	specific gravity	CQM	ASTM D854	1,466	0.15	239	11	0	0	0	0	231
	grain size (with hydrometer)	CQM	ASTM D422	1,466	2	3,188	147	0	0	0	0	3,079
	Atterberg limits	CQM	ASTM D4318	1,466	2	3,188	147	0	0	0	0	3,079
Sediment (Section 2.8) – Physical and Geotechnical, Only Where Capping is Being Considered												
	Triaxial compression	SET	ASTM D2850 and/or ASTM D4767 (requires undisturbed sample)	10–20	1	20	0	0	0	0	0	20
	SBLT	ARI	USACE D-94-1/Appendix D	4–5	1	5	0	0	0	0	0	5
Leachate from SBLT Test on Sediment (Section 2.8)												
	DOC	En Chem	WCM-2 and WCM-18	4–5	1	5	0	0	0	1	0	6
	TOC	En Chem	WCM-2 and WCM-18	4–5	1	5	0	0	0	1	0	6
	PCB as Aroclors	En Chem	SVO-8/SVO-77	4–5	1	5	0	0	0	1	0	6
Sediment												
	GEOTEK MSCL	NRT	TAMU SOP	1,466	1	1,466	73	0	0	73	0	1,612
	mineralogy by XRF	The Mineral Lab	XRF	40	1	40					0	40

Table 2-5
Number of Samples Processed Under Each Treatability Sequence

OU	Treatability (Process) Sequence	Total Number of Samples Processed Using This Protocol				
		Protocol A	Protocol B	Protocol C	Protocol D	Protocol E
3	A,B,D,E (To simulate hydraulic dredging, passive dewatering, wastewater treatment, land disposal)	Up to 30 core locations	6 total (5 discrete samples are generated from Protocol A, plus a blind duplicate) (For this sequence, coarse material separation is not performed.)	None	3 (Of the 6 samples processed through Protocol B, select 2 plus the duplicate.)	3 (All of the samples processed through Protocol D are forwarded to Protocol D.)
4	A,B,D,E (To simulate hydraulic dredging, passive dewatering, wastewater treatment, land disposal)	Up to 30 core locations	6 total (5 discrete samples are generated from Protocol A, plus a blind duplicate) (For this sequence, coarse material separation is not performed.)	None	3 (Of the 6 samples processed through Protocol C, select 3. No duplicate)	3 (All of the samples processed through Protocol D are forwarded to Protocol D.)
3	A,B,C,E (To simulate hydraulic dredging, mechanical dewatering, wastewater treatment, land disposal)	Up to 30 core locations	6 total (5 discrete samples are generated from Protocol A, plus a blind duplicate)	6	None	6 (Of the 6 samples processed through Protocol B, supernatant from 2 of them, plus the duplicate, are forwarded to Protocol E. Of the 6 samples processed through Protocol C, filtrate from 2 of them, plus the duplicate, are forwarded to Protocol E.)
4	A,B,C,E (To simulate hydraulic dredging, mechanical dewatering, wastewater treatment, land disposal)	Up to 30 core locations	6 total (5 discrete samples are generated from Protocol A, plus a blind duplicate)	6	None	6 (Of the 6 samples processed through Protocol B, supernatant from 2 of them, plus the duplicate, are forwarded to Protocol E. Of the 6 samples processed through Protocol C, filtrate from 2 of them, plus the duplicate, are forwarded to Protocol E.)

Table 2-6
Protocol A: Screening of Sediment Types to Select Samples to Subject to Treatability Testing

Step	Methods	Data Output and Uses
1	Evaluate existing sediment physical data (such as from the Remedial Investigation) and in-River conditions to determine if there are definable, spatial differences in sediment grain size gradation across each OU.	
2	If so, for each sub-OU, collect five to 10 randomly located sediment cores within the expected 1 ppm dredge footprint. If the OU cannot be subdivided on the basis of prior data and definable, spatial differences, collect 30 randomly located sediment cores within the expected 1 ppm dredge footprint from across the entire OU. (**Note:** These locations should be ones where there is a low likelihood that the PCB concentration exceeds 50 mg/kg, since the treatability laboratories may not be able to work with material above this threshold concentration.)	
3	Take two cores per location and preserve one. From the other, test for PCBs using the screening method. The PCB sample interval within the core shall be 10-centimenters .	The PCB result is an intermediate output only, not necessarily for final delineation of the extent of contamination above the action level. This intermediate determination is intended only to isolate the part of the core that is subject to dredging, and hence characterization for treatability purposes. Sediment below the expected dredge elevation can be discarded and need not be incorporated into the treatability program.
4	Based on the results from Step 3, identify the preliminary 1 ppm delineation in each core. This value shall be expressed as an elevation, using the project datum identified in Section 2.7.1. As a separate deliverable, report these values to the WDNR (with the corresponding x-y coordinate of the core) for purposes of an initial, tentative comparison to the existing interpolation of the 1 ppm contour.	
5	From the remaining core, analyze for grain size (ASTM D422) and Atterberg limits (ASTM D4318) within each major horizon. If the sediment column above the expected dredge elevation is uniform (i.e., essentially one horizon) and 4 feet in thickness or less, select at least two sample intervals from within the core. If uniform greater than 5 feet, select at least three sample intervals.	The grain size test results in a grains size curve and point values for various classification parameters (P200, d50, Cu, etc.). In combination with the Atterberg limits, these data are used collectively to establish the soil classification of the sample.
6	Plot the grain size distribution and identify the USCS classification for each sample (ASTM 2487).	

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Table 2-6
Protocol A: Screening of Sediment Types to Select Samples to Subject to Treatability Testing

Step	Methods	Data Output and Uses
7	Inspect the set of grain size curves and soils classification. On the basis of P200, d50, Cu, USCS designation, and professional judgment, identify at least five classes of sediment that represent the full range of physical characteristics for that OU. At a minimum, include separate classifications for the samples with the highest and lowest P200.	Note that this determination is only used as a way of collecting the widest possible range of material for treatability testing, on the basis of sediment physical properties. It does not have any other purpose in the context of the project or in the characterization of PCB impacts.
8	The core locations that generated the material within each of the sediment classifications identified in Step 7 constitute the locations from which material will be taken for treatability testing. The sampling crew will return to these locations to collect sufficient volume of sediment for the start of treatability work. A volume of River water will also be collected for the purpose of generating a simulated dredge slurry.	

Table 2-7
Protocol B: Slurry Pre-Processing and Thickening Prior to Dewatering

Step	Methods	Data Output and Uses
1	For each sediment sample collected as part of Protocol A (Step 8), perform a grain size analysis to confirm that the actual sample aliquot matches the intended classification. If not, the sampling crew shall return to the core location to collect additional material that matches the intended classification.	The grain size result is an intermediate output and is for informational purposes. It will be retained as part of the design record.
2	From among the set of samples, designate one sample as a blind duplicate. This blind duplicate will be processed in the same manner as the other samples.	
3	From the sediment solids and accompanying River water, create a simulated dredge slurry that is on the order of 8 percent solids. (This is intended to simulate the average, long-range solids concentration in a slurry from a hydraulic dredge.)	
4	For the sediment classifications that are comparatively high in sand, process the slurry using a fine screen or cyclone. (This is intended to simulate a full-scale hydrocyclone/screening operation, prior to thickening.) Record the mass of solids (both wet- and dry-weight basis) removed. A separation of at least 10 percent of the dry solids should be attempted.	The measurement of the mass retained is for informational purposes and to confirm that a given fraction of the total samples in the slurry has been removed.
5	Subject the de-sanded slurry to a column settling test, using the methods in USACE EM 1110-2-5027. Record suspended solids concentrations and other data as required by the test.	The results of the column settling test will be used to size and design a full-scale mechanical thickener, or a passive settling basin. The suspended solids in the supernatent represents the solids loading to the downstream clarification process.
6	Retain the thickened slurry for subsequent dewatering tests (Protocol C). Multiple settling tests may be needed on each sample to generate sufficient volume for the dewatering tests. Retain the supernatant from the column for subsequent wastewater testing (Protocol D).	For a mechanical system, the thickened slurry represents the feed to the downstream dewatering presses. For a passive system, the thickened slurry represents an intermediate point in what is expected to be a long-term (multi-year) drying and desiccation sequence.

Table 2-8
Protocol C: Testing of Mechanical Dewatering Characteristics and Dewatered Residuals

Step	Methods	Data Output and Uses
1	Thoroughly mix the thickened slurry obtained from Protocol B (Step 6). Measure the following in the slurry: • Percent solids (*Standard Methods for the Examination of Water and Wastewater*, Method 2540 G) It is expected that the initial solids concentration of the thickened slurry will be at least 15 percent. Split the sample so that sufficient volume is available for the testing of each dewatering process (minimum of belt press and filter press).	The percent solids test yields a discrete value for the thickened slurry. It represents the feed to the dewatering press. When presented on the basis of "dry tons of solids per hour" of feed, it is a common way of expressing the total dewatering capacity required.
2	Treat individual aliquots of sample with different chemical additives, and subject the treated aliquot to bench-scale filter and belt press testing. (The selection of the additive will be based on professional judgment and prior experience. At a minimum, the belt press tests will include conditioning with a polymer.) Retain the dewatered solids from each test.	The vendor's proprietary methods will yield information that is relevant to the sizing and design of specific dewatering equipment. The variability in performance at differing chemical additives will be reviewed to identify a preferred additive and dose for a full-scale system.

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Table 2-8
Protocol C: Testing of Mechanical Dewatering Characteristics and Dewatered Residuals

Step	Methods	Data Output and Uses
3	Analyze the dewatered solids for the following physical properties: • Percent solids (*Standard Methods*, 2540 G) (or use ASTM D2216 and convert water content to solids content) • Density (ASTM D2937) • Atterberg limits (ASTM D4318) • Compaction characteristics (ASTM D698) • Consolidation (ASTM D2435) • Unconsolidated-undrained triaxial compression test (ASTM D2850) • Consolidated-undrained triaxial compression test (ASTM D4767)	The individual test results will be used as follows: • Percent solids result is used to select the best operating condition and to identify the performance that should be achievable at full-scale. • The density result is used to convert the mass of filter cake generated to the equivalent volume (in cubic yards) that will be disposed. This volume is used in sizing the required disposal facility. • The Atterberg limits result is used to classify the filter cake as to its general behavior when disposed. • The compaction testing identifies the relationship between moisture content and density for a given compactive effort. This is used to specify the compaction requirements for placement of the waste in a landfill. • The consolidation test identifies the stress-strain relationship under future loading and the results are used to calculate long-term settlement of the waste mass in a landfill. • The triaxial compression tests yield values for cohesion and friction angle (expressed as “total” and “effective,” respectively.) The values are used in short-term and long-term slope stability calculations, respectively, for material placed in a landfill.
4	For each process option, review the results of Step 6 to confirm that the dewatered material achieves adequate percent solids and strength. For each process option, repeat Step 4 as necessary to determine a preferred chemical addition rate and press operating condition for full-scale application.	

Table 2-8
Protocol C: Testing of Mechanical Dewatering Characteristics and Dewatered Residuals

Step	Methods	Data Output and Uses
5	Based on Step 7, select the scenario that represents the best overall performance for each process option. Analyze the dewatered solids from that scenario for the following: • Column leaching test (ASTM D4874) Analyze the elutriate from the test for PCBs, metals, hardness, conductivity, pH, BOD, COD, ammonia, sulfate, and chlorides.	This result would simulate the leachate quality of waste disposed in a land-based unit. WDNR has expressed an interest in using this result to evaluate possible alternative liner designs.

Table 2-9
Protocol D: Testing of Characteristics of Passively Dewatered Residuals

Step	Methods	Data Output and Uses
1	The thickened slurry from Protocol B will be dried using passive or thermal methods to approximately 40 percent solids. Confirm drying by the following measurement: • Percent solids (*Standard Methods*, 2540 G) (or use ASTM D2216 and convert water content to solids content)	This processing step is intended to replicate the long-term drying and desiccation that is expected to occur over several years in the land-based drying beds (settling basins).
2	After drying, measure the consolidation properties of the material: • One dimensional consolidation (ASTM D2435, or equivalent seepage consolidation method appropriate for sediments)	This test generates a value for the coefficient of consolidation, a parameter that is used in settlement calculations for landfills.
3	The dried, consolidated solids will be characterized for the following: • Percent solids (*Standard Methods*, 2540 G) (or use ASTM D2216 and convert water content to solids content) • Density (ASTM D2937) • Atterberg limits (ASTM D4318) • Compaction characteristics (ASTM D698) • Unconsolidated-undrained triaxial compression test (ASTM D2850) • Consolidated-undrained triaxial compression test (ASTM D4767)	The individual test results will be used as follows: • Percent solids result is used to select the best operating condition, and to identify the performance that should be achievable at full-scale. • The density result is used to convert the mass of filter cake generated to the equivalent volume (in cubic yards) that will be disposed. This volume is used in sizing the required disposal facility. • The Atterberg limits result is used to classify the filter cake as to its general behavior when disposed. • The compaction testing identifies the relationship between moisture content and density for a given compactive effort. This is used to specify the compaction requirements for placement of the waste in a landfill. • The triaxial compression tests yield values for cohesion and friction angle (expressed as “total” and “effective,” respectively.) The values are used in short-term and long-term slope stability calculations, respectively, for material placed in a landfill.
4	Analyze the dried solids for the following: • Column leaching test (ASTM D4874) Analyze the elutriate from the test for PCBs, metals, hardness, conductivity, pH, BOD, COD, ammonia, sulfate, and chlorides.	This result would simulate the leachate quality of waste disposed in a land-based unit. WDNR has expressed an interest in using this result to evaluate possible alternative liner designs.

Table 2-10
Protocol E: Wastewater Clarification

Step	Methods	Data Output and Uses
1	This protocol is applied to a total of three simulated wastewater streams: the supernatant from the slurry settling tests (Protocol B), the filtrate from belt press dewatering test (Protocol C), and the filtrate from filter press dewatering test (Protocol C). For each sample, mix thoroughly. Measure the following: • Total suspended solids (TSS) (*Standard Methods*, Method 2540 D)	The percent solids value represents the solids concentration that would be seen by a full-scale clarification process. It is used for sizing of equipment and mass balance calculations.
2	Based on engineering judgment and prior experience, select a minimum of three chemical additives for jar testing. At least one additive should be a polymer. (In prior treatability work on Lower Fox River samples, alum provided the best performance and should be considered as one of the three additives.)	The jar testing results are used to select a chemical additive and to establish a dosage for a full-scale flocculation/coagulation unit.
3	For each simulated wastewater, perform jar tests at varying chemical doses. For each treatment, record observations, turbidity, etc., in accordance with usual practice.	
4	Repeat Steps 4 and 5, as needed, to select a preferred chemical additive and dose. Based on these results and engineering judgment, and at the option of the owner, Step 4 may be repeated at varying initial TSS concentrations using the preferred chemical additive and dose.	
5	For each of the three simulated wastewaters, select the preferred chemical additive and dose, and perform a column settling test on the treated sample (USACE EM 1110-2-5027). On the supernatent at designated intervals, measure the following: • TSS (*Standard Methods*, Method 2540 D)	The results of the column settling test are used in the design of the clarifier. The suspended solids measurement on the supernatent represents the concentration of solids in the feed to the downstream filters. It will be used in the sizing of those units.

Table 5-1
Preliminary Cost Estimate Pre-Design Characterization of OUs 1, 3 and 4[1]

Pre-Design Component	Estimated Budget
Base Mapping	
Survey Monuments	$65,000
Aerial Photography and Topographic Mapping	$140,000
Bathymetry and Sub-bottom Profiling	$400,000
Sidescan Sonar Survey	$125,000
Base map production	$80,000
1 ppm PCB Delineation	
Sediment Sampling	
OU 3	$150,000 - 300,000
OU 4	$250,000 - 500,000
Analytical[2]	
OU 3	$900,000 - 1,500,000
OU 4	$1,400,000 - 2,750,000
Sample Processing Facility[3]	$ 1,000,000 - 2,000,000
Engineering/Geotechnical Testing[4]	$300,000 - 750,000
Reporting and Data Management	$ 250,000 - 400,000
20% Contingency	> $ 1,250,000

1 Costs are preliminary estimates prepared for this initial planning phase. Given the uncertainty associated with the numerous assumptions at this stage of the planning process and no commitment to proceed to implementation no firm estimates from potential sub-contractors or vendors were obtained. Costs would be refined when competitive bids for this work are let or commitments to sub-contractors could be provided which can only follow decisions regarding actual implementation of this work plan are made.

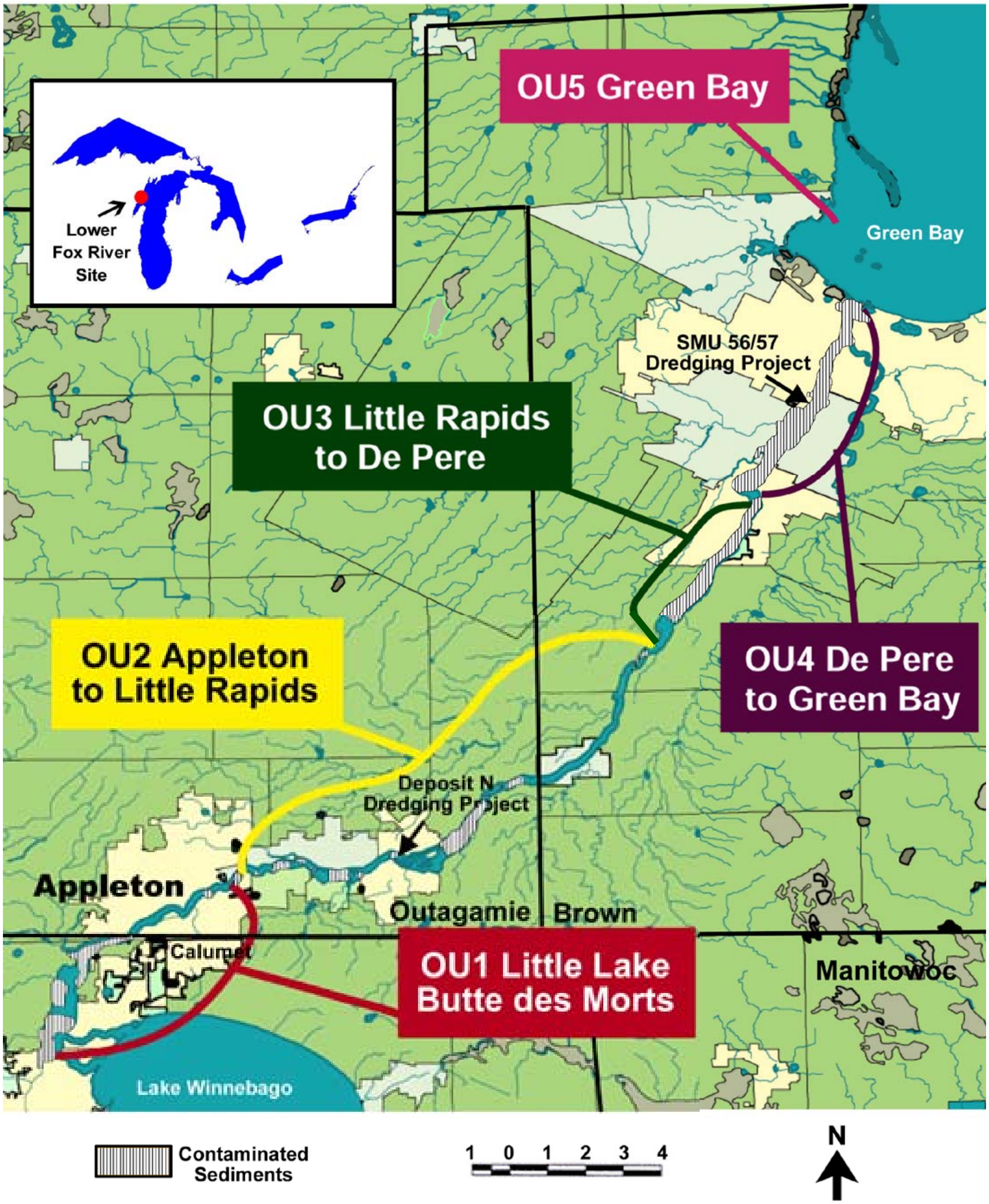
2 Range includes use of IA screening.

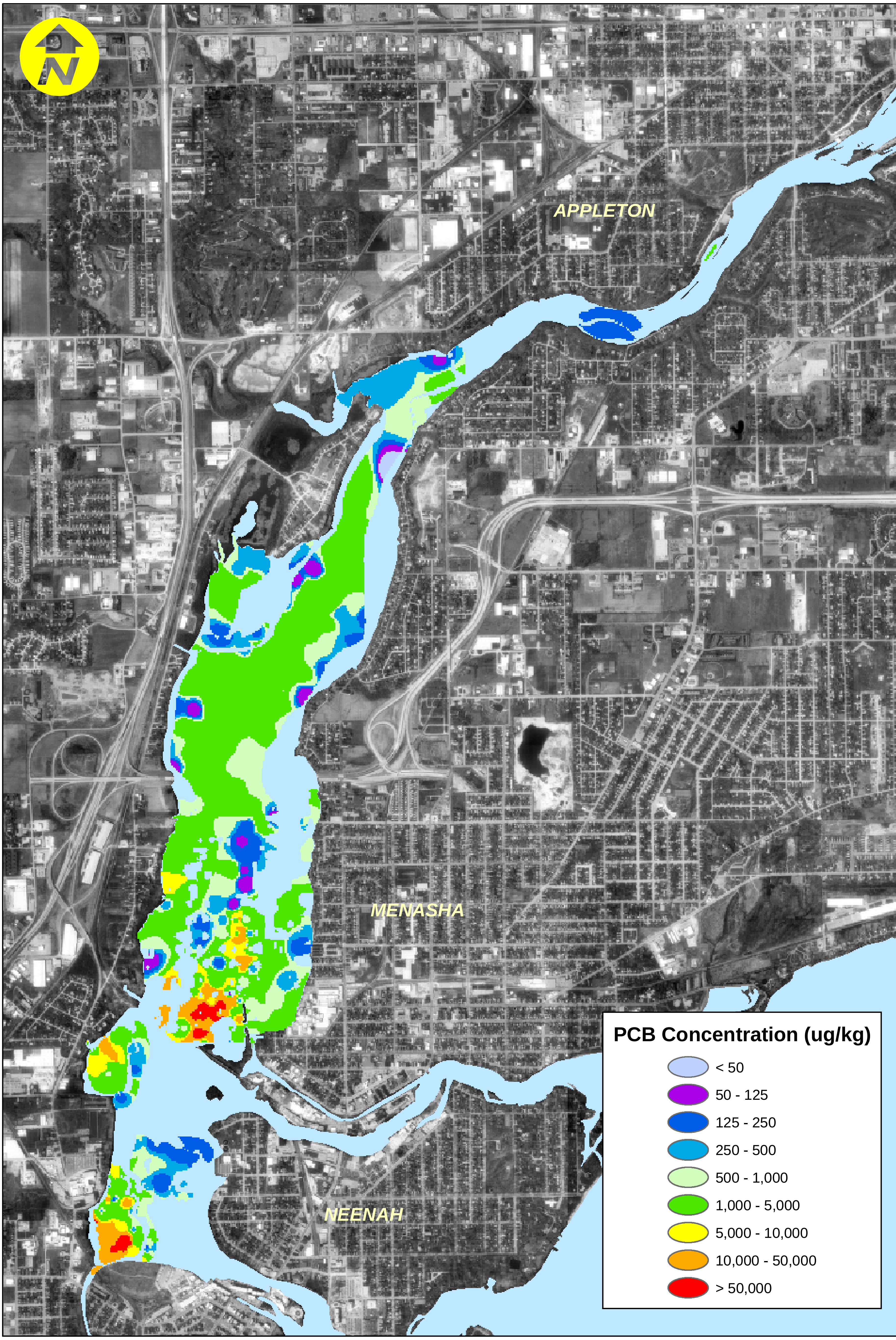
3 Based on the schedule contained in Figure 5-1 estimate includes facility lease (3 years), facility improvements (i.e., refrigeration, drying) GeoTek MSCL, and staffing (3 yrs, full time and seasonal staff).

4 Estimate includes testing identified in Sections 2.7 and 2.8. Vendors have not been contacted to obtain estimate but could be refined when potential vendors are contacted following implementation decisions.

Figures

Figure 1-1 Site Overview Map





0 2,000 4,000

1" = 2,000 Feet

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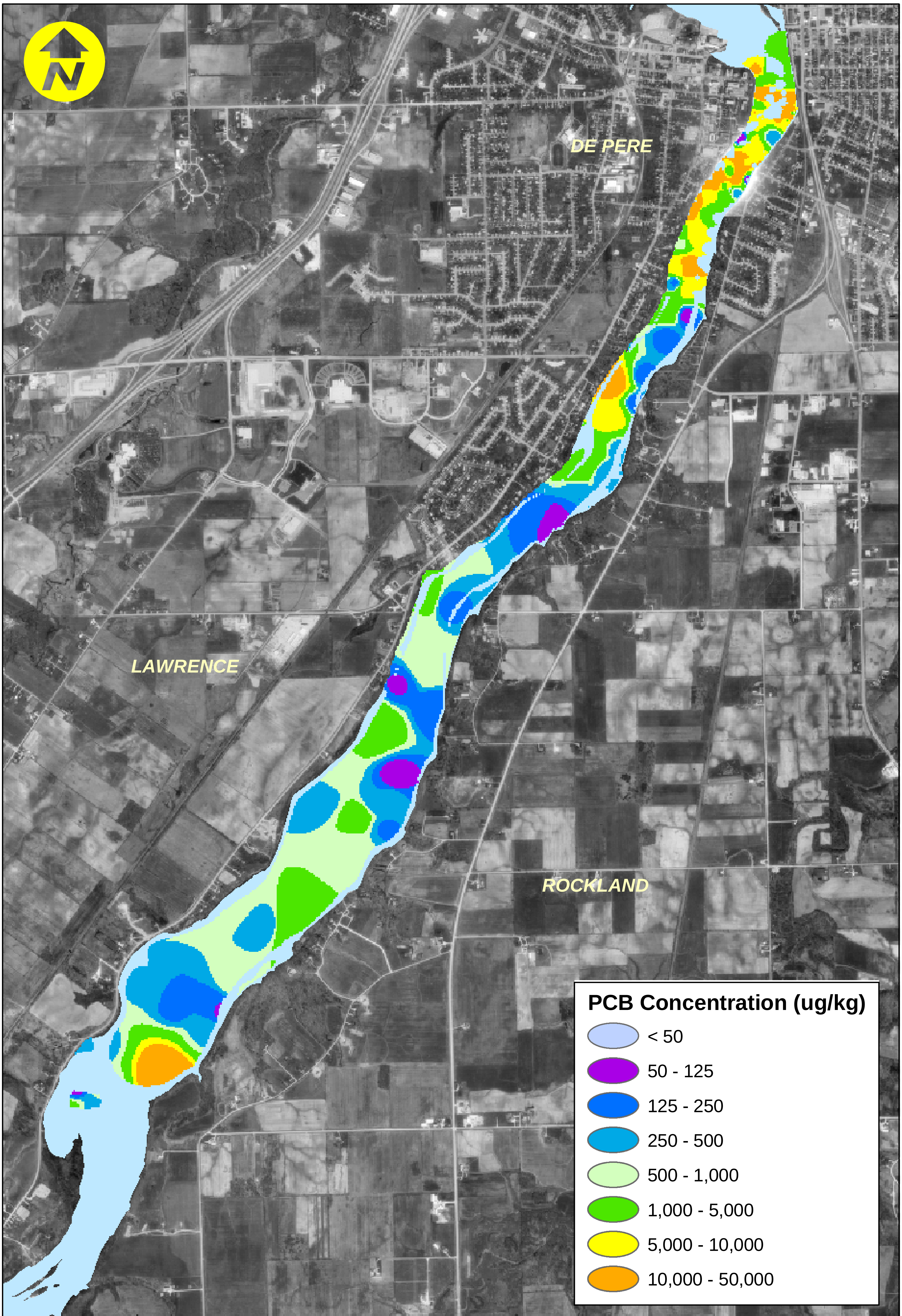
Operable Unit 1 Site Location Map

Lower Fox River, Wisconsin (WISC2-16495-110)

DISTRIBUTION OF INTERPOLATED PCB CONCENTRATIONS IN SEDIMENTS (0-10 cm): LITTLE LAKE BUTTE DES MORTS

DATE: 01/30/03		FILE: PCB Layer1B.mxd	FIGURE: 1-2



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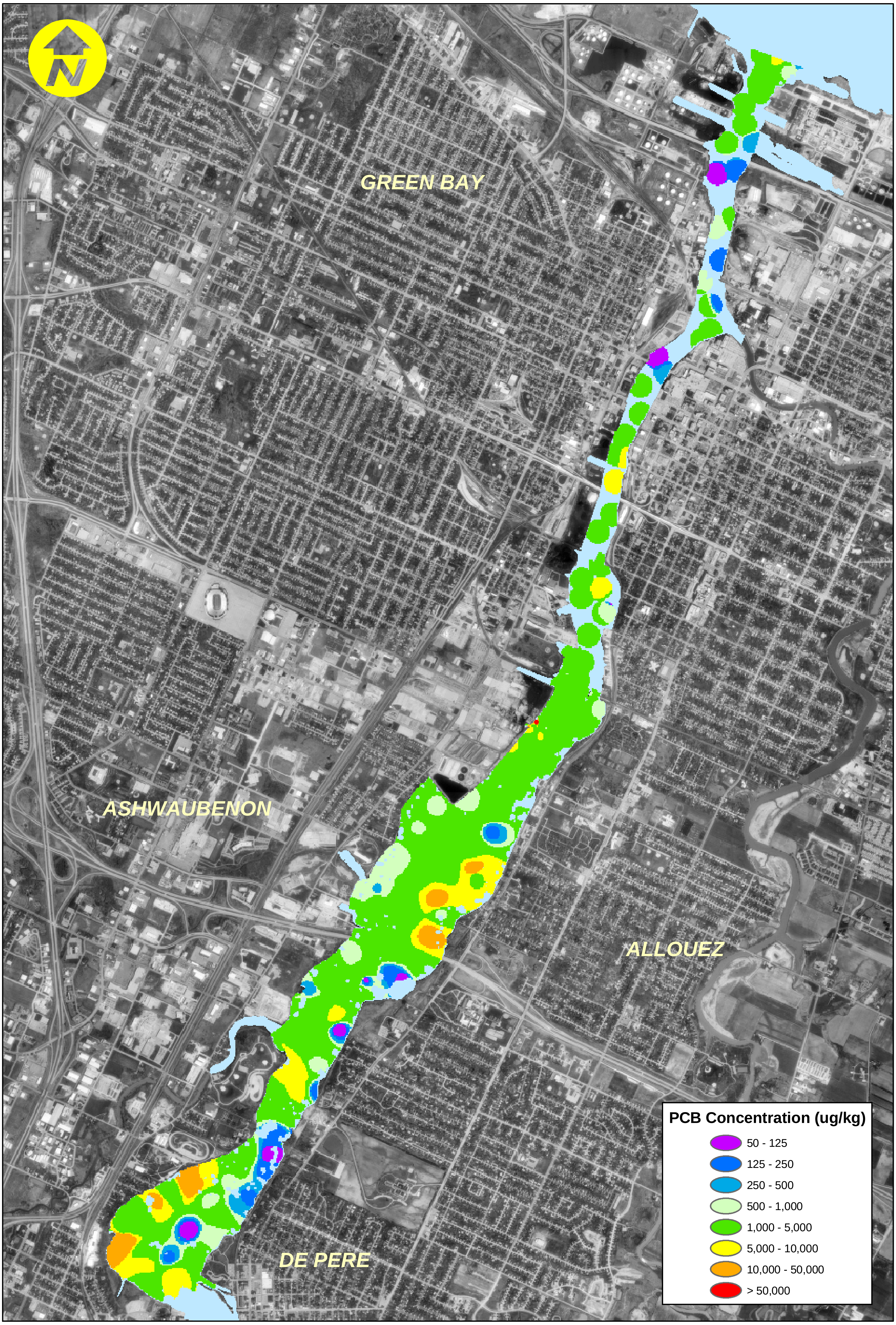
Operable Unit 3 Site Location Map

Lower Fox River, Wisconsin (WISC2-16495-110)

DISTRIBUTION OF INTERPOLATED PCB CONCENTRATIONS IN SEDIMENTS (0-10 cm): LITTLE RAPIDS TO DE PERE

DATE: 05/21/03 | FILE: Y:/15933/Maps/OU3/OU3 Layer1 PCB.mxd | FIGURE: 1-3



0 1,250 2,500 5,000

1" = 2,500 Feet

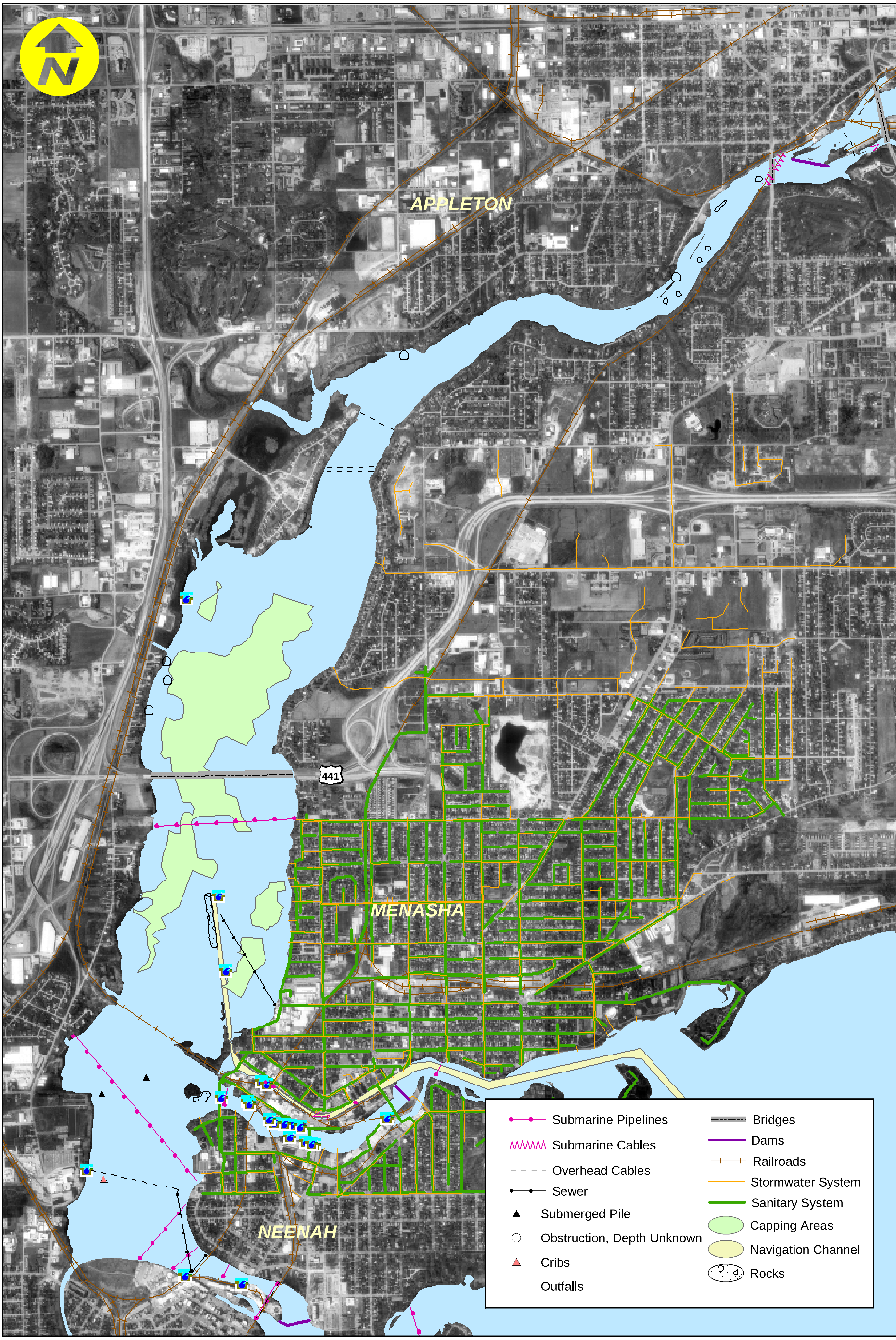
RETEC

Operable Unit 4 Site Location Map

Lower Fox River, Wisconsin (WISC2-16495-110)

DISTRIBUTION OF INTERPOLATED PCB CONCENTRATION IN SEDIMENTS (0-10 cm): DE PERE TO GREEN BAY

DATE: 05/21/03		FILE: OU4 Layer1 PCB.mxd	FIGURE: 1-4



0 2,000 4,000

1" = 2,000 Feet

RETEC

Operable Unit 1 Lower Fox River, Wisconsin (WISC2-16495-110)	**Navigation Channels & Infrastructure**

DATE: 04/21/03 | FILE: OU1 Infrastructure.mxd | FIGURE: 1-5

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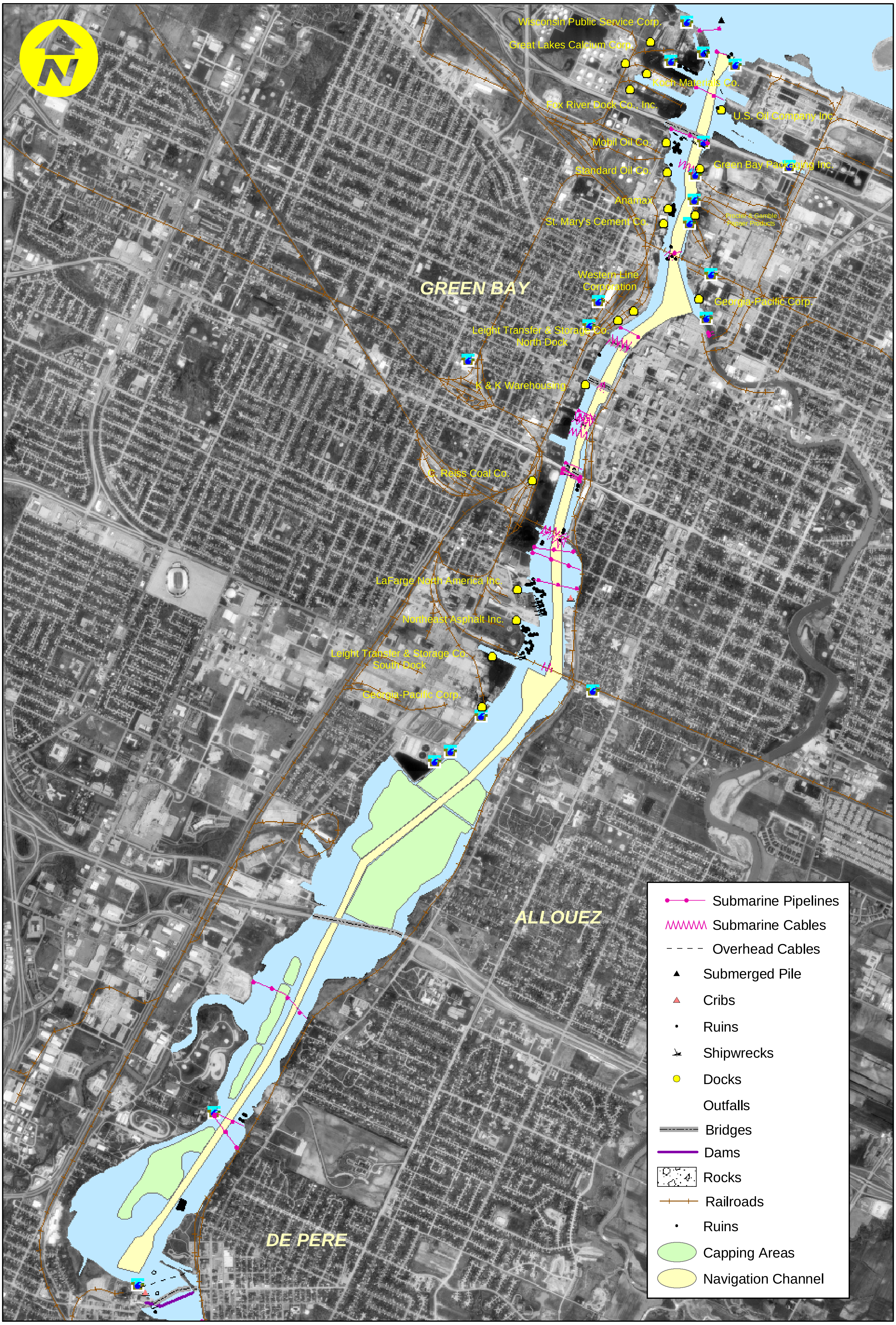
Operable Unit 3
Lower Fox River, Wisconsin (WISC2-16495-110)

Navigation Channels & Infrastructure

DATE: 04/28/03		FILE: OU3 Infrastructure.mxd	FIGURE: 1-6



0 2500 5000

1" = 2500 Feet

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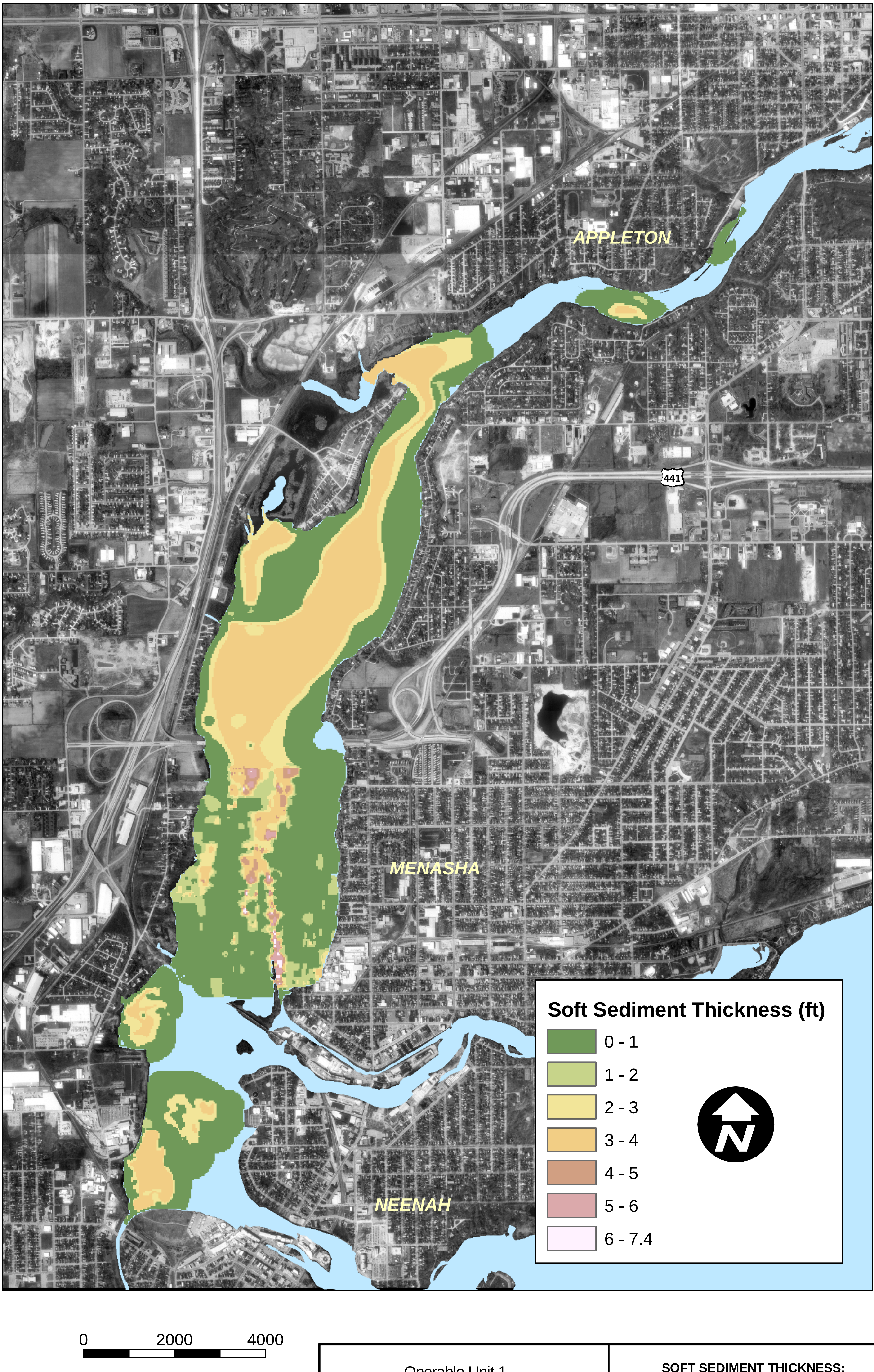
Operable Unit 4

Lower Fox River, Wisconsin (WISC2-16495-110)

Navigation Channels & Infrastructure

DATE: 05/01/03 | FILE: OU4 Infrastructure.mxd | FIGURE: 1-7



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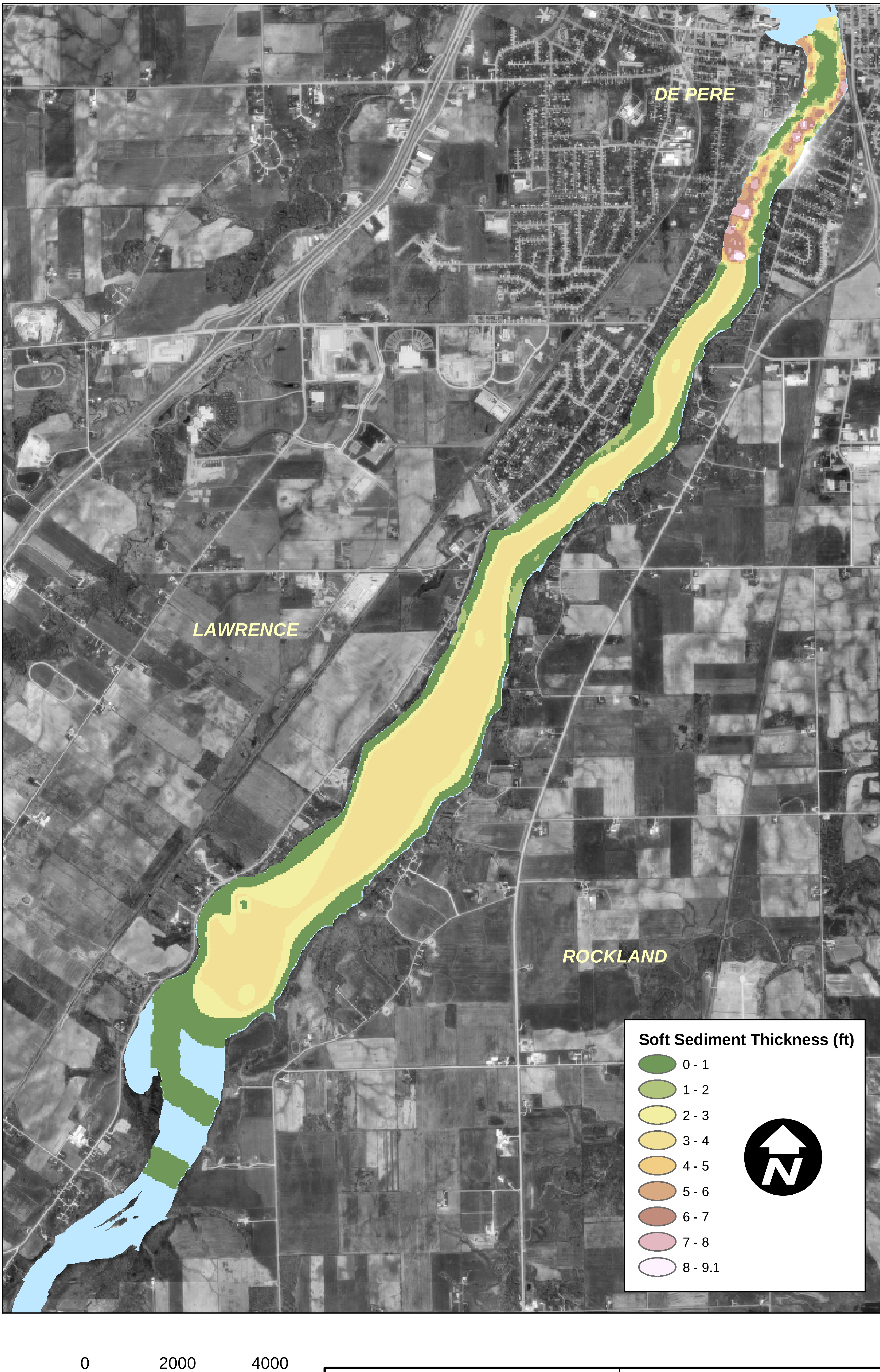
Operable Unit 1
Lower Fox River, Wisconsin (WISC2-16495-110)

SOFT SEDIMENT THICKNESS:
LITTLE LAKE BUTTE DES MORTS

DATE: 04/10/03 | FILE: OU1 XSection.mxd | FIGURE: 1-8



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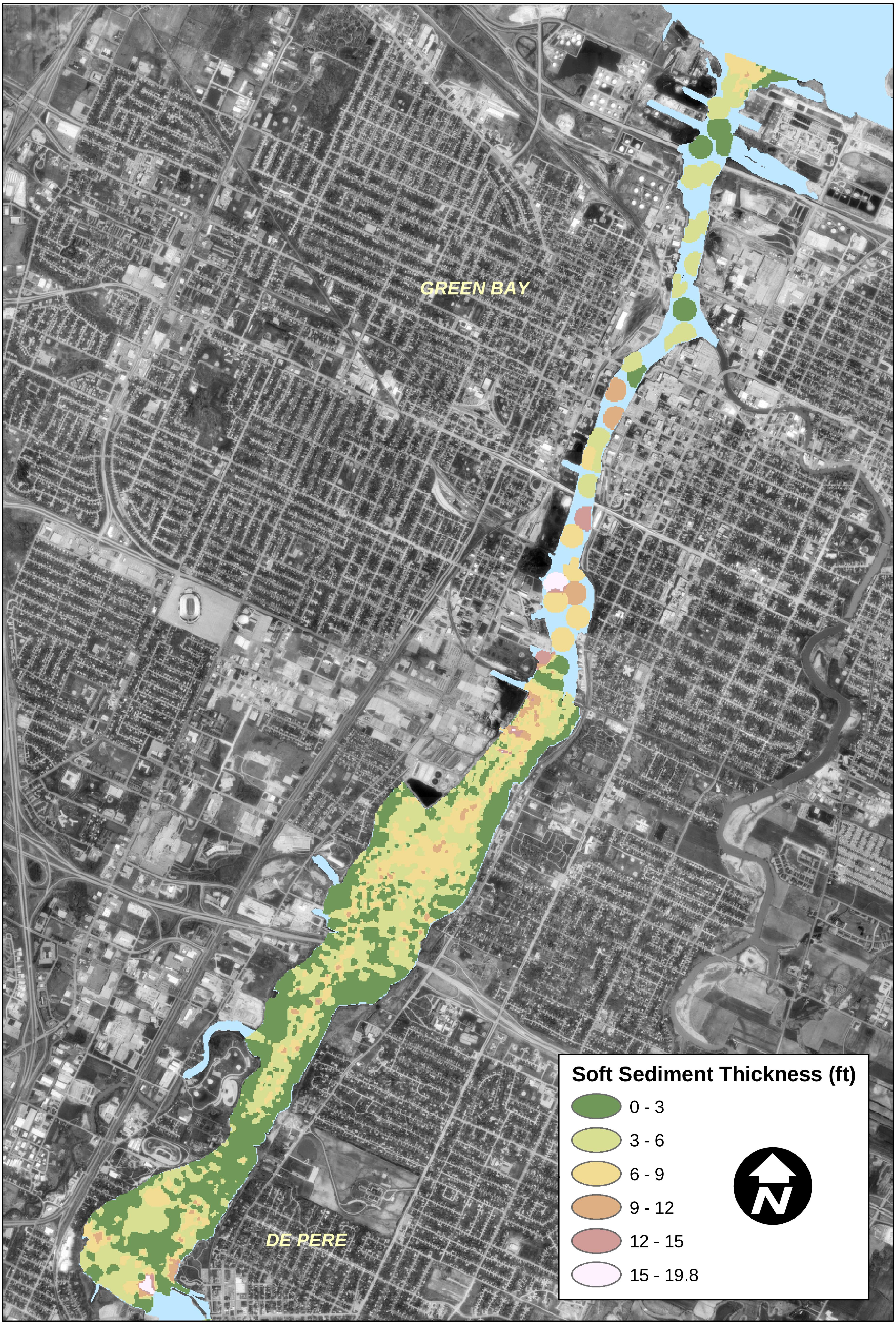
Operable Unit 3 Lower Fox River, Wisconsin (WISC2-16495-110)	**SOFT SEDIMENT THICKNESS: APPLETON TO LITTLE RAPIDS**

DATE: 04/28/03 | FILE: OU3 SoftSed Thickness.mxd | FIGURE: 1-9



0 2500 5000

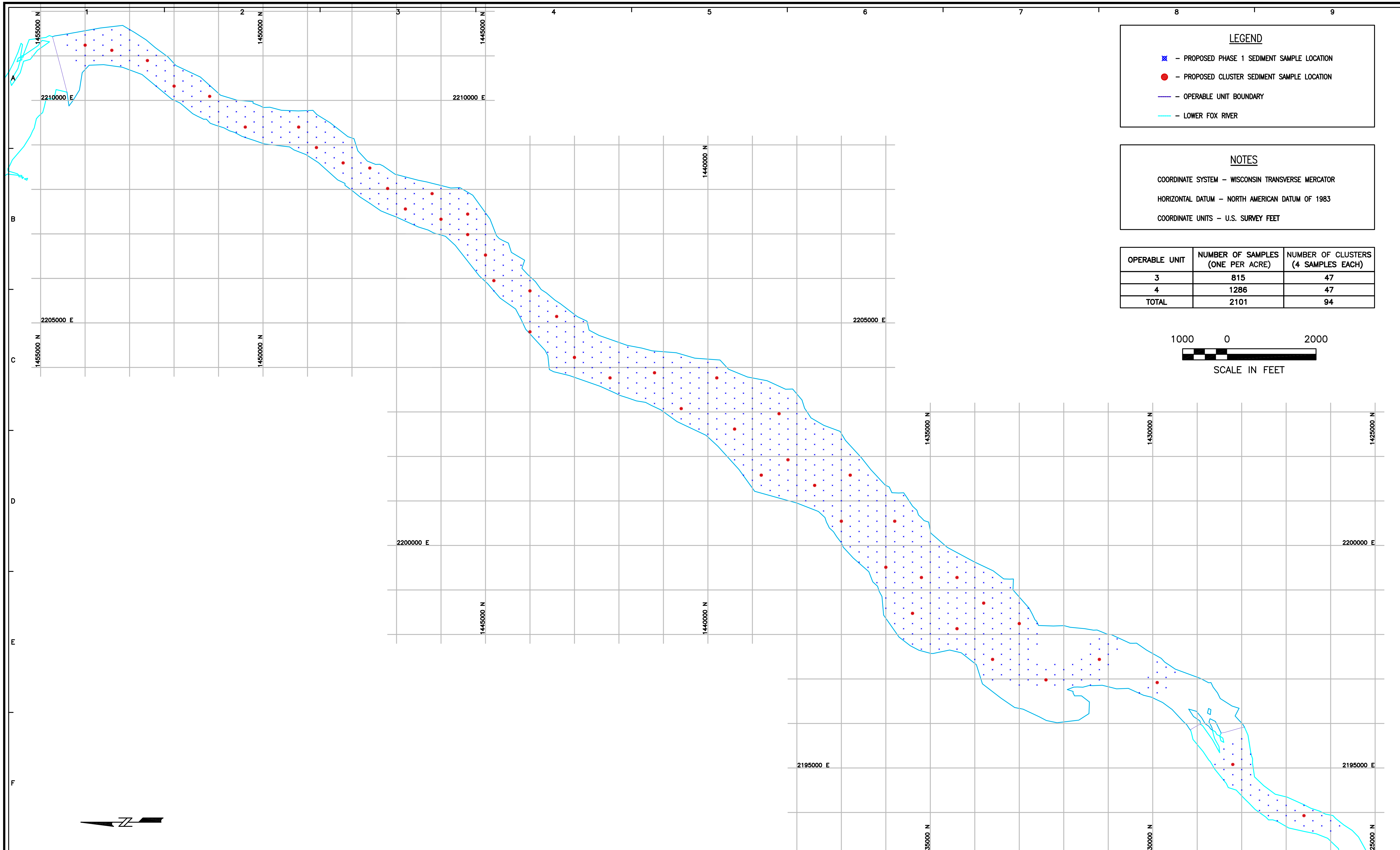
1" = 2500 Feet

RETEC

Operable Unit 4
Lower Fox River, Wisconsin (WISC2-16495-110)

SOFT SEDIMENT THICKNESS:
DE PERE TO GREEN BAY

DATE: 04/11/03	FILE: OU4 SoftSed Thickness.mxd	FIGURE: 1-10



LEGEND

- PROPOSED PHASE 1 SEDIMENT SAMPLE LOCATION
- PROPOSED CLUSTER SEDIMENT SAMPLE LOCATION
- OPERABLE UNIT BOUNDARY
- LOWER FOX RIVER

NOTES

COORDINATE SYSTEM – WISCONSIN TRANSVERSE MERCATOR

HORIZONTAL DATUM – NORTH AMERICAN DATUM OF 1983

COORDINATE UNITS – U.S. SURVEY FEET

OPERABLE UNIT	NUMBER OF SAMPLES (ONE PER ACRE)	NUMBER OF CLUSTERS (4 SAMPLES EACH)
3	815	47
4	1286	47
TOTAL	2101	94

1000 0 2000

SCALE IN FEET

RETEC

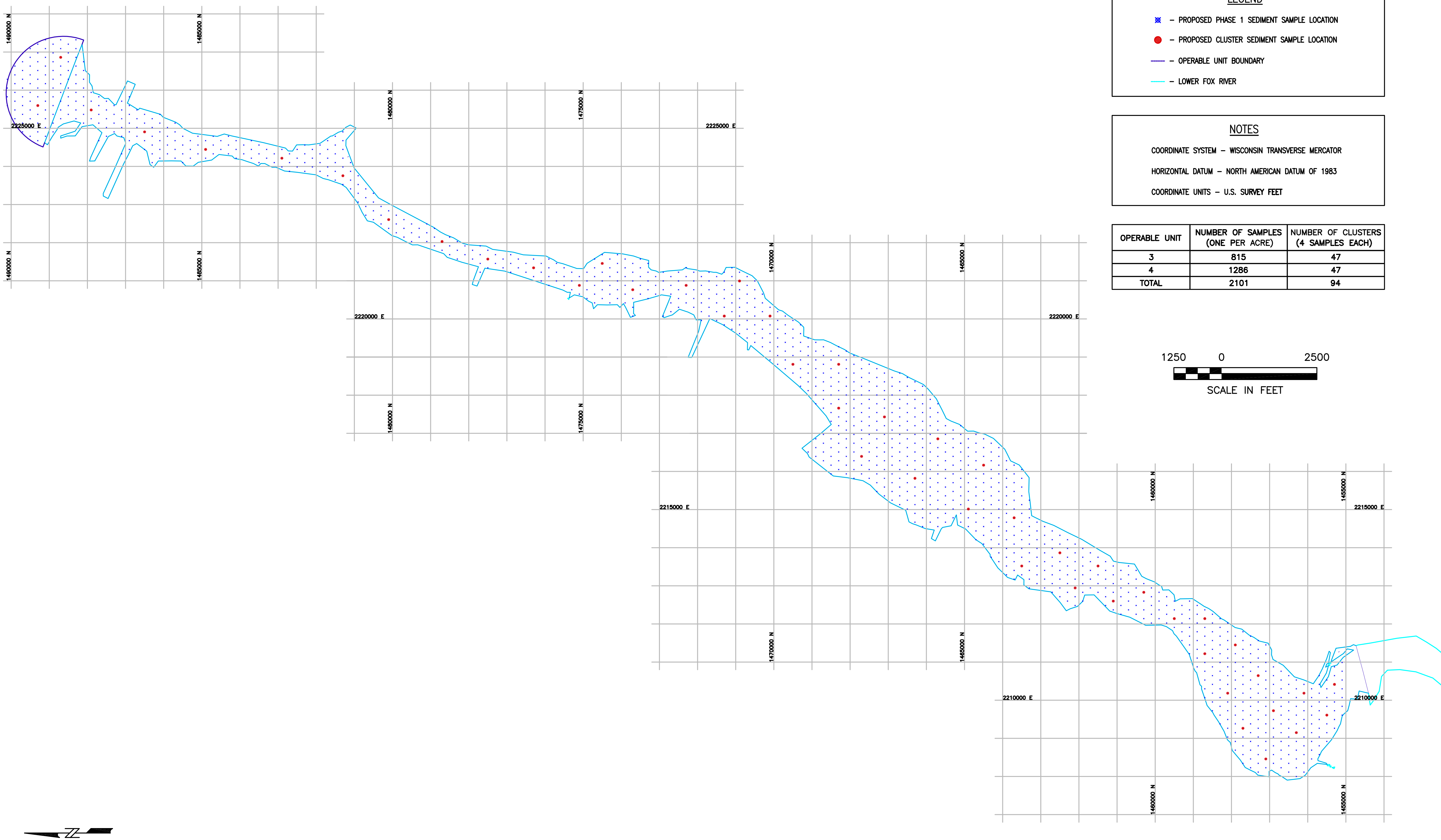
NO	DRWN	DATE	REVISION	CHKD	DATE	APPVD	DATE
1	MKM	10/03/03	MODIFICATIONS ACCORDING TO WDNR AND EPA COMMENTS	RLP	10/06/03		
0	MKM	07/01/03	PRE-DESIGN SAMPLING AND ANALYSIS PLAN	RLP	07/02/03		

PRE-DESIGN CHARACTERIZATION PROJECT
LOWER FOX RIVER
WISC2-16495-110

CURRENT DATE: OCTOBER 03, 2003 — FIGURE 2-1

PROPOSED SEDIMENT SAMPLE LOCATIONS
PHASE 1 AND CLUSTER SCHEMES
OPERABLE UNIT 3 AND DEPOSIT DD

DRAWING NO. LFRPD_SAP_SED-SAMPLES_P-1_OU3.DWG — REVISION 1



LEGEND

- PROPOSED PHASE 1 SEDIMENT SAMPLE LOCATION
- PROPOSED CLUSTER SEDIMENT SAMPLE LOCATION
- OPERABLE UNIT BOUNDARY
- LOWER FOX RIVER

NOTES

COORDINATE SYSTEM – WISCONSIN TRANSVERSE MERCATOR

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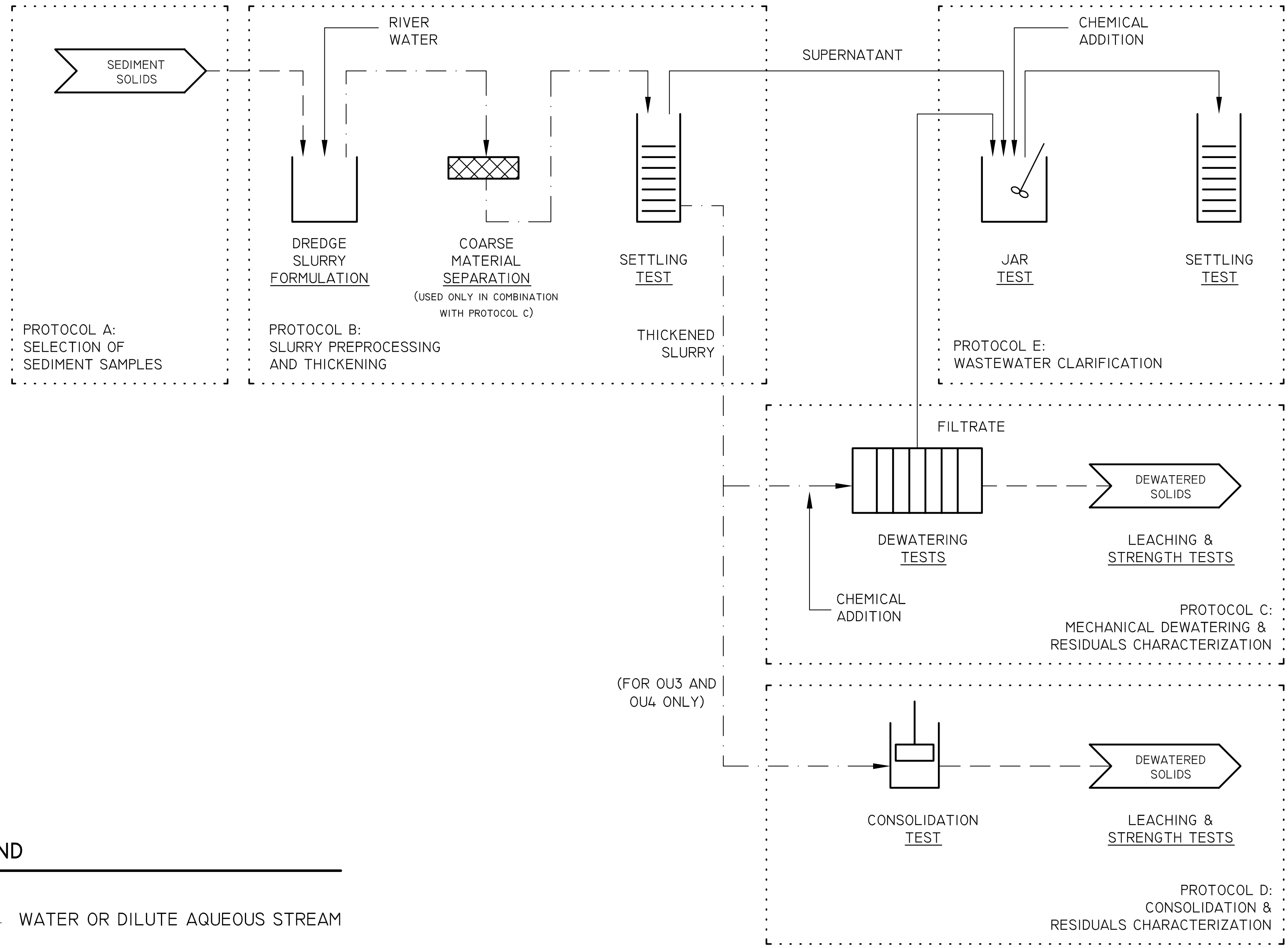
RETEC

NO	DRWN	DATE	REVISION	CHKD	DATE	APPVD	DATE
1	MKM	10/03/03	MODIFICATIONS ACCORDING TO WDNR AND EPA COMMENTS	RLP	10/06/03		
0	MKM	07/01/03	PRE-DESIGN SAMPLING AND ANALYSIS PLAN	RLP	07/02/03		

PRE-DESIGN CHARACTERIZATION PROJECT
LOWER FOX RIVER
WISC2-16495-110

PROPOSED SEDIMENT SAMPLE LOCATIONS
PHASE 1 AND CLUSTER SCHEMES
OPERABLE UNIT 4 AND GREEN BAY

CURRENT DATE: OCTOBER 03, 2003 | FIGURE 2-2 | DRAWING NO. LFRPD_SAP_SED-SAMPLES_P-1_OU4.PDF | REVISION 1



LINE LEGEND

WATER OR DILUTE AQUEOUS STREAM

SLURRY

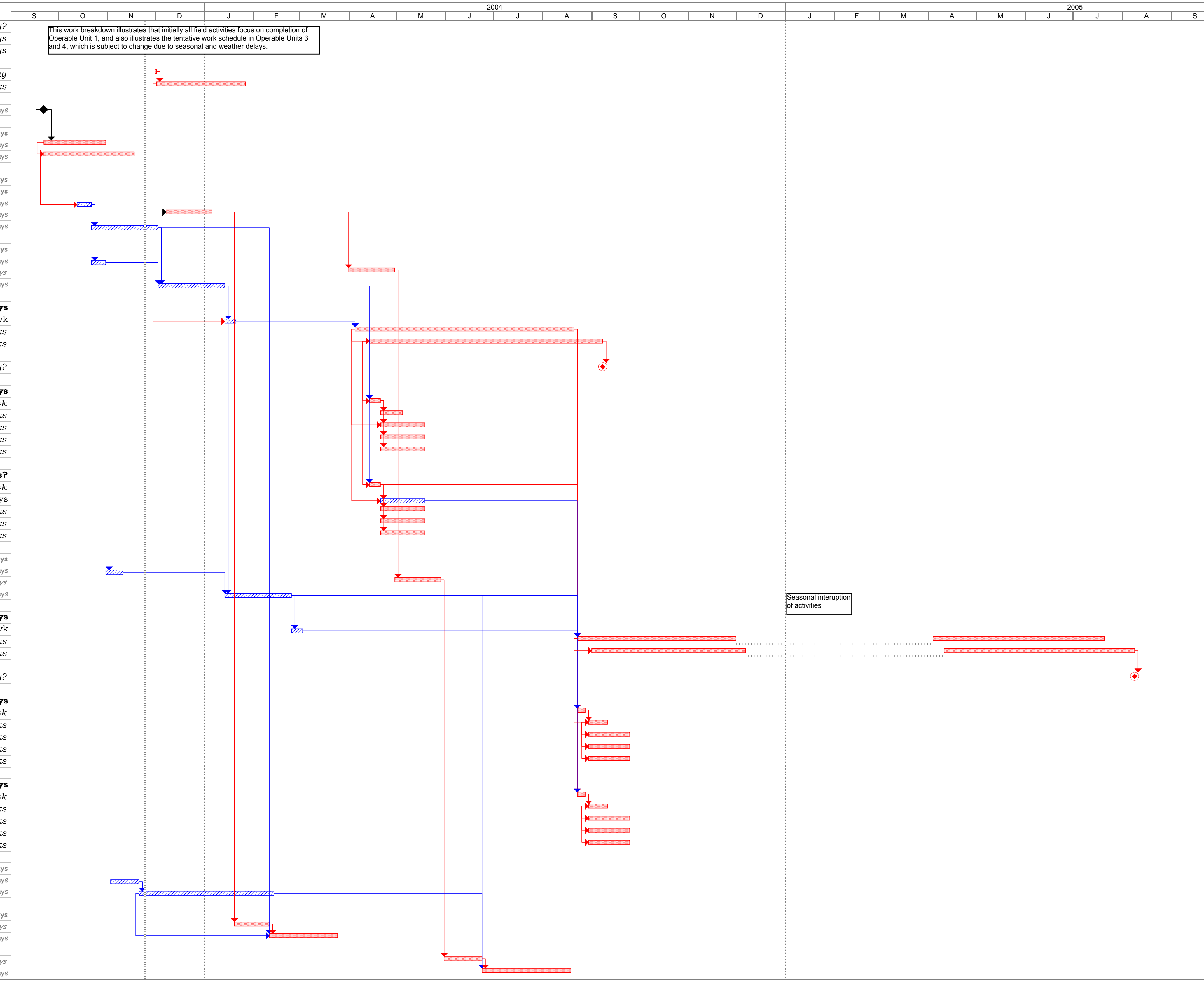
SOLID MATERIAL

RETEC

FIGURE 2-3
TREATABILITY TEST PLAN

FIGURE 5-1
WORK BREAKDOWN & SCHEDULE
[including work for Survey Control and Topographic and Bathymetric Mapping
an Lower Fox River (CO.Sai.05954.a)]

ID	Task Name	Duration
1	***PRE-DESIGN ACTIVITIES***	*1 day?*
2	*DRAFT PLAN REVIEW*	*30 days*
3	*REVISE DOCUMENTS*	*60 days*
4		
5	***NOTICE TO PROCEED SAMPLING FOR DELINEATION, CAPPING AND ENGINEERING GEOTECHNICAL***	*1 day*
6	*MOBILIZATION SAMPLING FOR DELINEATION, CAPPING AND ENGINEERING GEOTECHNICAL*	*8 wks*
7		
8	NOTICE TO PROCEED SURVEY & BATHYMETRY -Survey Control and Topographic and Bathymetric Mapping	0 days
9		
10	SURVEY CONTROL (Survey Control and Topographic and Bathymetric Mapping TASK 100)	40 days
11	ACCESS AGREEMENTS	28 days
12	FIELD WORK	40 days
13		
14	GEOPHYSICAL SURVEYS (Survey Control and Topographic and Bathymetric MappingTASK 300)	144 days
15	OU1	61 days
16	SIDESCAN SONAR AND SUB-BOTTOM PROFILING	7 days
17	BATHYMETRY	21 days
18	DATA PROCESSING AND INTERPRETATION	30 days
19		
20	OU3	137 days
21	SIDESCAN SONAR AND SUB-BOTTOM PROFILING	7 days
22	BATHYMETRY	*21 days*
23	DATA PROCESSING AND INTERPRETATION	30 days
24		
25	**PCB DELINEATION OU3**	**170 days**
26	REVIEW EXISTING DATA - LOCATE CORES	1 wk
27	*SAMPLE COLLECTION/ VANE SHEAR (in capping areas)/ MSCL*	*20 wks*
28	*ANALYTICAL TESTING*	*21 wks*
29		
30	***PHASE 2***	*1 day?*
31		
32	**CAPPING GEOTECHNICAL OU3**	**25 days**
33	*REVIEW EXISTING DATA/ LOCATION OF CORES*	*1 wk*
34	*SAMPLE COLLECTION/ VANE SHEAR*	*2 wks*
35	*TRIAXIAL*	*4 wks*
36	*SBLP*	*4 wks*
37	*POREWATER*	*4 wks*
38		
39	**ENGINEERING GEOTECHNICAL OU3**	**463 days?**
40	*REVIEW EXISTION DATA - LOCATE CORES*	*1 wk*
41	SAMPLE COLLECTION	20 days
42	*FILTRATE SAMPLES*	*4 wks*
43	*LEACHATE TESTING*	*4 wks*
44	*PRESS SAMPLES*	*4 wks*
45		
46	OU4	151 days
47	SIDESCAN SONAR AND SUB-BOTTOM PROFILING	7 days
48	BATHYMETRY	*21 days*
49	DATA PROCESSING AND INTERPRETATION	30 days
50		
51	**PCB DELINEATION OU4**	**379 days**
52	REVIEW EXISTING DATA - LOCATE CORES	1 wk
53	*SAMPLE COLLECTION/ VANE SHEAR (in capping areas)/ MSCL*	*47.6 wks*
54	*ANALYTICAL TESTING*	*48.8 wks*
55		
56	***PHASE 2***	*1 day?*
57		
58	**CAPPING GEOTECHNICAL OU4**	**25 days**
59	*REVIEW EXISTING DATA/ LOCATION OF CORES*	*1 wk*
60	*SAMPLE COLLECTION/ VANE SHEAR*	*2 wks*
61	*TRIAXIAL*	*4 wks*
62	*SBLP*	*4 wks*
63	*POREWATER*	*4 wks*
64		
65	**ENGINEERING GEOTECHNICAL OU4**	**25 days**
66	*REVIEW EXISTION DATA - LOCATE CORES*	*1 wk*
67	*SAMPLE COLLECTION*	*2 wks*
68	*FILTRATE SAMPLES*	*4 wks*
69	*LEACHATE TESTING*	*4 wks*
70	*PRESS SAMPLES*	*4 wks*
71		
72	AERIAL PHOTOGRAPHY (Survey Control and Topographic and Bathymetric Mapping TASK 200)	75 days
73	DATA ACQUISITION	14 days
74	DATA PROCESSING AND INTERPRETATION	61 days
75		
76	MAPPING (Survey Control and Topographic and Bathymetric Mapping TASK 400)	152 days
77	OU1 BED ELEVATION CONTOURING	*16 days*
78	OU1 PRODUCTION	31 days
79		
80	OUS 3 AND 4 BED ELEVATION CONTOURING	*18 days*
81	OUS 3 AND 4 PRODUCTION	40 days



Draft printed: 11/24/2003

Appendix A

Standard Operating Procedures and Field Forms

GRANULAR SEDIMENT CLASSIFICATION

1.0 GENERAL

Granular sediment is material for which percentages of individual components that make up the sediment can be determined. The sediment description and identification scheme presented herein is based upon visual inspection and manual testing. Sediment description and identification can be broken down into two main categories; class of material, and physical parameters. This sediment classification guideline is based upon ASTM D 2488-00, Standard Practice for Description and Identification of Soils (Visual-Manual Procedure).

2.0 SEDIMENT CLASSESS

Granular sediment is comprised of three classes of material, biogenic, mineral/lithic, and glass. Glass is likely to be only a minimal component so it does not warrant further discussion. The descriptive classification for both mineral and biogenic types is based upon grain-size and sediment constituents.

2.1 Biogenic (Organic) Sediments

Biogenic sediments (organic origin) are those that contain remains or traces of once-living organisms in a concentration of greater than 50%. This class of sediment is often flocculent at the sediment/water interface and has a “pudding-like” texture due to its high content of organic material. Biogenic sediments are often dark brown to black in color, and have an organic odor. Basic components of those sediments include; shell fragments, fish parts, plant material, and fecal pellets.

2.2 Mineral Sediments

Mineral sediments consist of mineral grains derived from physically weathered rocks, precipitates and authigenic sources in a concentration of greater than 50%. For the definitions of clay, sand, and silt, section 3 of ASTM Standard D2488 should be consulted. If there are enough biogenic/organic constituents present to influence the soil properties, ASTM D2488 section 14.8 should be consulted. Common components of mineral sediments include; quartz, feldspars, clay minerals, micas, and rock fragments.

3.0 PHYSICAL PARAMETERS

Physical descriptions derived from visual observation and manual testing can be used to classify sediment origin (biogenic or mineral) as well as physical properties of the material. The physical sediment description includes the following parameters:

- Color;
- Odor;
- Obvious materials;
- Structure;
- Consistency (including particle size, shape and angularity for course grained-sediments);
- Gradation;
- Dry Strength (manual test);
- Dilatancy (manual test);
- Toughness (physical description); and,
- Plasticity (physical description).

The sediment color should be identified using a Munsell® soil color chart. Often organic sediments (biogenic) turn color after exposure to air, any such color change should be noted as well.

The odor of a sample should be described if it is organic or is petroleum or chemical. If the odor does not fall into those categories, describe as best as possible.

Any obvious material in samples, such as coal fines, metallic chips, wood, etc. should be noted, and depth of material recorded. Further, any sheen on the water surface due to sediment disturbance should also be recorded.

The structure of the sediment should be described utilizing the following table taken from ASTM D-2488.

TABLE 7 Criteria for Describing Structure

Description	Criteria
Stratified	Alternating layers of varying material or color with layers at least 6 mm thick
Laminated	Alternating layers of varying material or color with layers less than 6 mm thick
Fissured	Breaks along definite planes of fracture with little resistance to fracturing
Slickensided	Fracture planes appear polished or glossy, sometimes striated
Blocky	Cohesive soil that can be broken down into small angular lumps which resist further breakdown
Lensed	Inclusion of small pockets of different soils, note thickness
Homogeneous	Same color and appearance throughout sample

Consistency for fine-grained sediments (50% or more fines) of biogenic or mineral sources should be described as very soft to very hard utilizing the following table taken from ASTM D-2488.

TABLE 5 Criteria for Describing Consistency

Description	Criteria
Very soft	Thumb will penetrate sediment more than 1 in. (25 mm)
Soft	Thumb will penetrate sediment about 1 in. (25 mm)
Firm	Thumb will indent sediment about ¼ in. (6mm)
Hard	Thumb will not indent sediment but readily indented with thumbnail
Very hard	Thumbnail will not indent soil

Consistency for course-grained sediments (less than 50% fines) should include several descriptive observations; particle size, particle shape, and angularity. Particle size differentiates between sand, silt and clay. The definitions of sand, silt and clay can be found in ASTM D2488 Section 3.1. Particle shape refers to the length, width, and thickness of the individual particles. The description of particle shape should only be used in cases where the particle shape is flat, elongated, or flat and elongated as define by Table 2 from ASTM D 2488.

Table 2 Criteria for Describing Particle Shape

Flat	Particles with width/thickness >3
Elongated	Particles with width/length >
Flat and elongated	Particles meet criteria for both flat and elongated

The angularity refers to the overall shape or outline of a particle. The description should either be angular, sub-angular, sub-rounded or rounded as defined in Table 1 taken from ASTM D2488.

TABLE 1 Criteria for Describing Angularity of Coarse-Grained Particles

Description	Criteria
Angular	Particles have sharp edges and relatively plane sides with unpolished surfaces
Sub-angular	Particles are similar to angular description but have rounded edges
Sub-rounded	Particles have nearly plane sides but have well-rounded corners and edges
Rounded	Particles have smoothly curved sides and no edges

Gradation refers to the distribution of grain sizes present in a sample and should be used where course-grained sediments are encountered. The description should be either well-graded or poorly-graded as defined in sections 15.31 and 15.32 of ASTM D 2488.

For fine-grained mineral sediments, dry strength, dilatancy, toughness and plasticity should be used to classify the material as lean clay, fat clay, silt or elastic silt. For further information on individual

manual tests, tables 8 through 12 in section 14 of ASTM D 2488 should be consulted and/or the NRT Fine-grained Soils Field Identification sheet which is based on the ASTM standards.

4.0 CHECKLIST for SEDIMENT DESCRIPTION

The following is a checklist for describing and classifying sediments. Appropriate visual inspection and manual testing should be recorded on the field log.

1. Class type (Biogenic or Mineral,)
2. Color using a Munsell® soil color chart (in moist condition, note color change when exposed to air for biogenic sediments)
3. Odor (organic, chemical, etc.)
4. Any obvious materials (coal fines, metallic chips, wood, sheen, etc.)
5. Note any structures (fissured, lens, etc.)
6. Consistency, including particle-size range, shape, and angularity for coarse-grained sediments
7. If mineral sediment decide whether sediment is fine grained (<50% fines)or course grained (>50% fines)
8. If fine grained do the following manual tests to determine whether the sediment is a lean clay, fat clay, silt or elastic silt as defined by ASTM 2488 section 14.7:
   - Dry strength;
   - Dilatancy;
   - Toughness, and,
   - Plasticity.
9. If course grained, describe the sediment as sand or gravel per guidelines presented in ASTM D 2488 section 15. The following visual observations should also be noted:
   - Particle size
   - Particle shape
   - Angularity
   - Gradation

7.0 REFERENCES

1. ASTM, 2000. Standard Practice for Description and Identification of Soils (Visual-Manual Procedure). ASTM D-2488-00.

2. Sediment Sampling guide and Methodologies (2nd Edition), United States Environmental Protection Agency, Division of Surface Water, Cincinnati, Ohio, 2001.

VIBRO-CORE SAMPLING

1.0 GENERAL

The vibro-corer is an electrical powered sediment sampling system featuring a vibrator head that drives a core tube (often containing a cellulose acetate butyrate (CAB) liner) into the sediment. Liners can be up to 20 ft (6 m) long and 4 inch inside diameter; lengths are selected based on sediment measured. The following SOP explains the technique for collecting sediment core samples using a vibro-corer. The procedures cover the following activities:

- Site position.
- Securing the barge for sampling.
- Sampling procedure.

2.0 EQUIPMENT and SUPPLIES

The following equipment and supplies would be needed for a typical sampling at one station:

- Vibro-corer (including core tube)
- Winch
- CAB core tubes
- Core catcher
- Stainless steel bowls and spatulas
- HDPE sediment sample bottles
- Glass bottles for organic contaminant samples
- Ice chests
- Labels
- Markers/pencils
- GPS or other locational equipment
- Generator
- Heavy duty riveter and aluminum rivets
- Battery powered cordless drill
- Battery powered cordless saw
- Personal protection equipment (i.e., hard hats with face shields, gloves, Tyvec ™suits, steel toed boots, safety glasses)
- Core caps
- Duct tape

3.0 COLLECTION PROCEDURES

A sampling activity may include collecting more than one type of sample at a site. This procedure will detail the collection of sediment core samples from a site location. When benthic organism samples are being collected at the same site, it is important to collect benthic organism samples prior to the collection of sediment samples to minimize disturbances of the benthic organisms. All sampling activities should be cleared with Digger's Hotline or equivalent to mark all utility structures, cables, and pipelines.

3.1 Sample Location

The sample location may be either defined prior to sampling, or the site can be selected during the sampling procedure. Sites should be located with a Differential Global Positioning System (DGPS) with has an accuracy of less than a meter. Actual locational readings should not be recorded until the barge is anchored at the sampling site. The location should be verified after coring to confirm position. Data should be recorded in latitude and longitude in North America Datum (NAD).

3.2 Securing the vessel

The sampling vessel should be triple anchored, moored to a secure fixture or spudded prior to collecting cores.

3.3 Sample Procedure

The following procedure is a suggested method to collect sediment core samples:

1) Measure the water depth and soft sediment thickness.

2) Insert core catcher into CAB tube.

3) Position core catcher, drill holes, and rivet into place with aluminum rivets.

4) Lift the vibrating head with the winch to a vertical position so that it is suspended just off the bow of the sampling vessel.

5) Insert the core tube into the vibrating head, making sure that the tube slides in all the way.

6) Tighten the collar to the vibro-corer (two bolts on each side).

7) Lower the entire assembly until the core nose is just above the sediment surface. Care should be taken to ensure that the cutter head or end of the core tube does not come into contact with the vessel during deployment. Verify that the generator is on. Turn on the vibrating head.

8) Slowly lower the vibro-corer by running out 6-10 inches of cable at a time. Monitor core tube penetration by feeling for slack in the cable. Note appropriate rate of penetration in field log.

9) When the vibro-corer ceases to penetrate the sediment (stops lowering or is "refused"), or the vibrating head is near the sediment surface, reverse the winch and pull the unit from the sediment. Do not allow the vibrating head to become imbedded into the sediment.

10) Turn off the power to the vibrating head when the core breaks free of the sediment.

11) During retrieval, the coring device and core tube need to be maintained in a vertical position to minimize disturbance of the collected sediments. Lift the assembly so that the sediment/water interface is visible. Wash the excess sediment from the outside of the tube. Once out of the water, the cutter head should be inspected and a physical description of the material at the mouth of the core entered into the core log. Drill holes through tube at the sediment/water interface and decant water from tube.

12) Tie line around tube in a single or double clove hitch.

13) Disengage tube lay sediment core on the deck. Approximately 2 cm above the apparent sediment-water interface, drill a hole in the CAB liner to remove overlying water. The sediment water interface is defined as the level that does not behave like water when the core is manipulated (*i.e.*, the sediment remains in place when the core is tipped). The overlying water may contain fluffy or flocculent materials that are decanted off with the overlying water. The hole is drilled 2 cm above the apparent sediment surface to allow for some consolidation of the more dense fluff material. Saw off excess core liner at the approximate level of the drilled hole. Place a cap plug on the liner and secure with duct tape. Both ends should then be secured tightly with duct tape to prevent leakage. The amount of sediment in the tube should be measured and recorded in the sample log, along with the overall condition of the core. The core tube then should be marked to denote the following:

- Station identification;
- Sediment recovery;
- Bottom and top; and,
- Date and time sampled.

14) Handle and subsample core as desired, either on board or at a shore based location. The core sample should be transported only in an upright position if not immediately processed on vessel.

4.0 REFERENCES

1. Sediment Sampling guide and Methodologies (2nd Edition), United States Environmental Protection Agency, Division of Surface Water, Cincinnati, Ohio, 2001.

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MULTIPLE TRANSDUCER (ARRAY) BATHYMETRY

Equipment Overview:
Multiple transducer sonar systems (termed "Array" systems) are designed to collect multiple depth measurements along a line running perpendicular to the travel path of the survey vessel (called the vessel 'swath'). This enables array systems to collect thousands of data points per hour, covering a survey area in a fraction of the time it would take a single transducer system to do the same. The result is a reasonably detailed bathymetric survey, supported by data point coverage on a fixed interval. The primary advantage of an array system is the limited amount of draft needed to operate the transducers, as well as to provide data spacing at a regular interval between receptors. These systems are best suited to large expanses of extremely shallow water (between 2' and 20' of water depth) where a high level of contour detail is required.

In addition to positioning and heading, array systems must compensate for the heave, pitch and roll motions of the vessel they are attached to. A GPS unit, a gyro, and a motion reference unit (MRU) must be incorporated into the system to tie positioning to the depth points and to correct for vessel motion. The final component of an array system is software to integrate and control the individual pieces of hardware. In most cases the software links the hardware outputs together, calculates and applies corrections to the data in real-time, and provides a navigation module. Like commercial single-beam and multi-beam systems, array systems can be adjusted to reflect changing sound velocities and are fully automated in their collection of data.

The array system used for this project is manufactured by Ross Laboratories, and is called the **Ross Mini/Smart Sweep** system. The system designed with 8 single-beam transducers set 5 feet apart from each other for a total swath width of 40 feet. To accomplish this, two booms are outfitted to the survey vessel with 3 transducers mounted onto each. When the booms are extended outward from the vessel, each of the 6 transducers are spaced 5' apart from each other creating the total swath width perpendicular to the travel of the vessel. Two additional transducers are mounted through the hull of the survey vessel to complete the total swath width of 40', with soundings collected every 5' along the swath.

The transducers used in the Ross Mini/Smart Sweep system operate at a **frequency of 200kHz**, and have switchable **beam widths between 11° and 22°**. Ross transducer units are capable of receiving sounding measurements in water depths of 1.5 feet to over 200 feet below the face of the unit. In our configuration, the draft (distance between the face of the transducer and the top of the water) of each transducer can be adjusted from 6 inches to 18 inches; thus giving the system the ability to survey area as shallow as 2 feet of water depth.

Our Mini/Smart Sweep system is mounted to a pontoon-style vessel. This configuration is ideal for inland shallow water operations in that it provides a very stable platform with a minimal amount of vessel draft (estimated between 14 & 18 inches including the outboard drive). The vessel is outfitted with a **TSS Standard** gyro and **"DMS 2"** motion reference unit (MRU) for heading determination and heave/pitch/roll compensation. We will use an **Applied Microsystems** sound velocity **"Smart Sensor"** to provide values for the speed of sound in water (more accurate than the standard "bar check" method). In an effort to obtain added accuracy, a **Trimble MS750/4800** RTK system **with horizontal and vertical centimeter level positioning accuracy** will be used to provide vessel positioning.

Calibration:
Two types of calibration checks will be conducted: a transducer accuracy test and a sediment penetration test. The transducer accuracy test will verify that each transducer in the array is recording water depths correctly on a daily basis. This is accomplished by extending a plate below each transducer to a known fixed depth. The known plate

depth is then compared to the depth reported by each transducer to verify their individual accuracy. Any deviations will be corrected prior to collecting the data.

The second calibration check is the sediment penetration test, which attempts to determine how deep the array system transducers are penetrating into the soft sediments of the bottom. Onyx will perform a sediment penetration test once per survey matrix (roughly 50 to 60 acres in area). A steel plate (10 inches square by 0.5 inches thick, weighting roughly 14 lbs.) attached to a graduated rule will be lowered into the water adjacent to one of the inboard transducers. Once on bottom, the depth from the surface of the water to the steel plate will be recorded along with the depth reported by the adjacent transducer. No adjustments will be made in the field to the transducers to correct for differences observed between the two measurements.

In addition, a sound velocity profile will be conducted once per matrix surveyed. The average will be computed from the profile and used as the speed of sound input for the collection software on that day. Onyx-SS will use a Smart SV sound velocity profiler manufactured by Applied Geomechanics for creating the velocity profile. The sensor will be lowered into the water column and stopped at 2-foot increments to obtain the profile. The actual profile data will be applied to the data collected that day during post processing.

Survey Setup:

Water depth, current, and site configuration will be reviewed prior to deployment of the array system. Upon review, a pre-designed survey track-line plan (running with the river flow where possible) and survey matrix will be entered into the HyPack navigation software. The trackline plan will position parallel tracklines (set 40 feet apart from each other) within the matrix to be surveyed. Tracklines will extend the full width of the river and will be used as reference/guidelines for completing each matrix. Matrices are pre-defined survey blocks which are "filled" with data as the array vessel passes through them (refer to the e-document "HyPack Max Operation Manual" for details on program operation).

The array transducers will be deployed to a draft between 6 and 18 inches, depending on the depths anticipated in that day's survey matrix and weather conditions. Survey speed will be held between 3 and 5 knots in areas with greater than 5 feet of water depth, and 2 to 3 knots in all other areas. The gyro, MRU, and RTK systems will all be mounted in the same horizontal centerline position ("stacked" on top of another) on the vessel; thus eliminating all but vertical offsets for each piece of equipment. The position of the MRU will be considered the origin for offsets on the vessel (x=0, y=0, z=0). Each array transducer will have a unique horizontal offset; however they will all have the same vertical offset (or draft).

Survey geodesy for the HyPack navigation software will be set in State Plane (NAD83) Wisconsin Central (4802) with the vertical datum of NAVD 88. Navigation input for the Marine Sonic sonar will come directly from the RTK system (GLL & GGA @ 9600 baud).

Daily Survey Procedure

The array survey crew will consist of two crewmembers (1 vessel operator and 1 sonar technician). Prior to launching the vessel, the survey crew will setup the RTK positioning system over one of the pre-surveyed benchmarks within the area to be surveyed that day (refer to the RTK Positioning SOP document for details on this procedure). A technician will also adjust the draft of the individual transducers for the weather and anticipated survey conditions within that day's survey matrix.

Next the tech will power-up the topside sonar PC, which activates the Ross Labs SmartSweep collection software. The hardware will be setup to transmit on a short pulse (SH), narrow beam width (11° angle) configuration. Once the operation of the SmartSweep system is confirmed, the array vessel will be launched and the sonar technician will power-up the HyPack Max 2.11c navigation software (refer to the e-document "HyPack Max Operation Manual" for details on program operation). The survey trackline plan and matrix for the days survey activities will be loaded and displayed for the vessel operator to follow.

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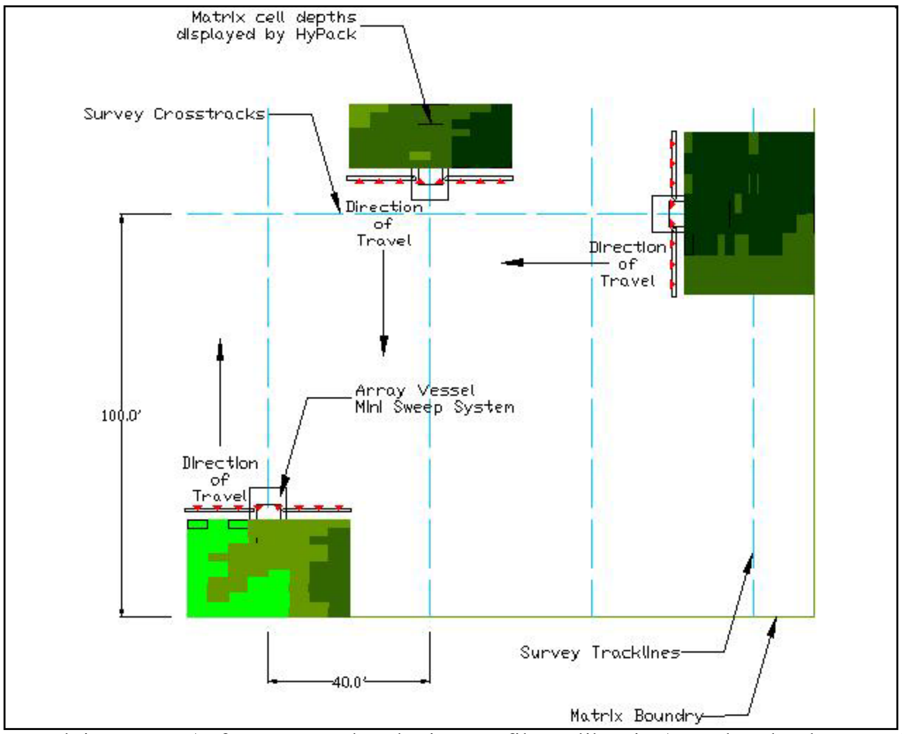
The vessel operator will navigate to the anticipated deepest area within the matrix to collect a sound velocity profile and to conduct the first calibration test (transducer Accuracy test). When completed, the vessel will navigate to the center of the matrix to conduct the second calibration test (sediment penetration test). Finally, the crew will navigate the vessel to the nearest datum gage and record the measurement and time. Periodic manual datum measurements (1 to 4 hour time intervals, depending on the amount of change observed) from datum gages in the survey area will be collected as a backup to the RTK system output.

Once the system is setup, calibrated, and operating satisfactory to the client representative, the survey will begin. The matrix surveyed will be completely filled with data, using the track-line plan as a guide. The array vessel will collect data at a 5-foot interval (40-foot swath track) within the matrix, as well as running perpendicular crosstracks at 100-foot intervals. Each matrix will be broken up into cells measuring 5-foot wide (swath) by 2-foot long (along vessel track). Once data is collected in a cell, HyPack will be configured to "fill" the cell (the color the cell is filled with will correspond with a depth scale) with the average corrected depth obtained from all of the soundings recorded within it. This allows the operator to have a real-time view of bottom depths as well as identify where the vessel has collected data.



Both SmartSweep and HyPack save data collected to their respective harddrives within a folder labeled with the day's date. The depths saved by SmartSweep are referred to as "uncorrected" depths in that they are the actual depths recorded by each transducer based on the average speed of sound in water (refer to sound velocity profile calibration). The depths saved by HyPack are referred to as "corrected" depths in that these depths have been corrected for transducer draft, heave/pitch/roll movements of the vessel, and horizontal position/elevation changes obtained by the RTK positioning system.

All frequencies, configuration settings, and survey progress with the area track-line plan will be recorded on the daily survey log. A copy of this log showing the information recorded each day is included with this SOP.

Project Safety

Onyx's basic marine safety policy includes steel toes safety shoes, life vests, and hard hats when working with overhead equipment. For this project, we will be conducting all survey operations from the survey vessel *Array Surveyor,* a Coast Guard compliant pontoon vessel with marine radio and onboard cellular phone. Prior to launching at any site, Onyx will obtain phone numbers and radio channels for hailing facility staff and key project personnel. Once contacts are identified, everyone will be notified of the day's events and schedule that pertain to them. In addition, Onyx will broadcast notices on the marine emergency channel 16 at regular intervals throughout the day as to our whereabouts and progress.

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SIDE SCAN SONAR SYSTEM

Equipment Overview:
Commercial side scan sonar has many applications. Its primary application in survey work is target/debris identification and location. DGPS is employed to give targets/bottom outcrops a location; as the data is converted to a real-time visual image. These images are saved and cataloged for re-interpretation at a later date. The side scan sonar unit produces an image off one or both sides of the unit (each side identified as a left or right channel). The range of the sonar is determined by the transmitted frequency of the unit; and is usually operator defined. The higher the sonar frequency, the better the resolution of the image collected and the smaller the range in which the sonar can survey.

For the purpose of this survey, a dual frequency (**600 kHz x 150 kHz**) sonar will be used to obtain images of the river bottom. The unit will be hard mounted to the survey vessel, utilizing **only one channel** at a time for increased image detail. The range will be limited to **50 meters, which corresponds to a survey track-line spacing of 150 feet at 10% overlap.** We will use a **Trimble MS750/4800** RTK system **with horizontal and vertical centimeter level positioning accuracy**. Overall accuracy of the side scan images is dependent on accurate estimations of sonar unit layback (the horizontal distances between the towed sonar unit and the DGPS beacon); **we anticipate the overall accuracy of side scan images to be centimeter level due to the hard mount design**. All raw images will be saved to CD and provided to the client along with a viewing program. A high frequency (**1200 kHz**) **Side Scan Sonar made by Marine Sonics** will be available for detailed images of crucial areas.

Calibration:
Calibration checks will be conducted once daily on any available control structure extending below the water surface (i.e. bridge piers, pilings, boat docks, etc…). These checks will be performed by saving an image of the control structure on both the left and right channels. The two images will be recorded to disk and re-opened in the Marine Sonic viewing program "SeaScan Review" (refer to the SeaScan and SeaScan Review Manuals for details on program operation). The position of the control structure will be recorded on each image and compared for accuracy.

In addition, a sound velocity profile will be conducted once a week. The average will be computed from the profile and used as the speed of sound input for the collection software. Onyx-SS will use a Smart SV sound velocity profiler manufactured by Applied Geomechanics for creating the velocity profile.

Survey Setup:
Water depth, current, and site configuration will be reviewed prior to deployment of the sonar. Upon review, a pre-designed survey track-line plan (running with the river flow) will be entered into the HyPack navigation software. The trackline plan will position parallel tracklines (set 120 feet apart from each other) within the area to be surveyed. The line spacing will allow for sonar image overlap greater than 10% at a range of 50 meters. The tracklines will extend the full width of the river for complete coverage of the survey area.

The side scan sonar is typically deployed to a depth equal to between 8% and 20% of the range (approximately 12 to 30 feet at a 50-meter range). However, due to the shallow depths associated with the OU's, the depth will be held between 2' and 7' on a fixed mount. Survey speed will be held between 3 and 5 knots in areas with greater than 5 feet of water depth, and 2 to 3 knots in all other areas. Positioning accuracy will be greatly enhanced with the use of the hard mount for the tow fish in that the sonar layback will be fixed with no need for computation.

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Survey geodesy for the HyPack navigation software will be set in State Plane (NAD83) Wisconsin Central (4802) with the vertical datum of NAVD 88. However, the Marine Sonic side scan sonar software only collects data in geographic coordinates, so all sonar images will the geo-referenced in latitude and longitude (DDM). The navigation input for the Marine Sonic sonar will come directly from the RTK system (GLL & GGA @ 4800 baud).

Daily Survey Procedure

The side scan survey crew will consist of two crew members (1 vessel operator and 1 sonar technician), with one of the crew members being a lead surveyor within the Onyx-SS hydrographic survey group. Prior to launching the vessel, the survey crew will setup the RTK positioning system over one of the pre-surveyed benchmarks within the area to be surveyed that day (refer to the RTK Positioning SOP document for details on this procedure). The sonar technician will then attach the tow fish to the fixed mount and connect the umbilical. Next the tech will power-up the top-side sonar PC, activate the SeaScan image collection software, and have the vessel operator assist in performing a "rub test" on the tow fish to confirm the system is operational. The rub test is accomplished by activating the tow fish, setting the sonar gains at their highest levels, and then physically rubbing the left and right transducers of the tow fish by hand. The sonar technician will observe signal spikes on the sonar image, indicating that the fish and the topside PC are communicating.

Once the operation of the side scan system is confirmed, the survey vessel will be launched and the sonar technician will power-up the HyPack Max 2.11c navigation software (refer to the e-document "HyPack Max Operation Manual" for details on program operation). The survey trackline plan for the days survey activities will be loaded and displayed for the vessel operator to follow. The vessel operator will navigate the vessel to the control structure to confirm sonar accuracy. Along the way, the sonar technician will deploy the tow fish and set the sonar gains. Once the gains are set and satisfactory to the client representative, the control structure will be imaged and recorded for review.

Once the review is complete and satisfactory, the survey will be conducted according to the track-line plan. Sonar images will attain 95% bottom coverage of the survey area for that day. The SeaScan software will be set to automatically record images along the survey tracklines with a 10% along-track overlap. The software saves individual image (*.mst) files and navigation files within a folder labeled with the day's date.

When changes in water depth dictate, the image gains and sonar depth (deployed deeper as water depth increases) will be fine adjusted on the fly in order to obtain the best image resolution possible. In an effort to limit the amount of adjustment needed, the survey track-line plan will be set up to maintain similar depths along each survey track. All test and final images will be copied onto CD(s) at the end of each day.

All frequencies, configuration settings, and survey progress with the area track-line plan will be recorded on the daily survey log. A copy of this log showing the information recorded each day is included with this SOP.

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SUB-BOTTOM PROFILING SONAR SYSTEM

Equipment Overview:

Sub-bottom profiling is used to create an image of both the river/lake bottom and the various sediment/soil layers beneath it. The sub-bottom profiler produces an image by keying off of the different densities of objects and/or geologic features of the river bottom. In some cases, these images can be used to identify vegetation, wood, steel, light sediments, clay, sand, and bedrock in a particular area.

Onyx-SS will use an Edgetech 216S with the X-Star processor, which is capable of penetrating the subsurface to a depth of 50m. The unit will be towed along side the survey vessel and utilize a **fluctuating frequency range between 2 and 16 kHz**. The range will be limited to **50 meters, which corresponds to a survey track-line spacing of 150 feet at 10% overlap.** We will use a **Trimble MS750/4800** RTK system **with horizontal and vertical centimeter level positioning accuracy**. Overall accuracy of the sub-bottom profiling images is dependent on accurate estimations of sonar unit layback (the horizontal distances between the towed sonar unit and the DGPS beacon); **we anticipate the overall accuracy of sub-bottom profiling images to be within 1 foot due to the shallow water towing arrangement**. All raw data will be saved to digital tape, then converted to CD for presentation to the client.

Calibration:

Calibration checks are typically conducted on an available control structure below the water surface (i.e. a known/charted rock outcrop). These checks are performed by saving a line of data, which crosses over the control structure, and comparing its position to the charted position at a later date. Unfortunately in this area there are no known or charted rock outcrops with which to do this with. In addition, these check are generally performed during the post processing of the data, which does not allow for adjustment in the field. However, we will be collecting side scan data simultaneously with the sub-bottom survey and both systems will use the same positioning input directly from the RTK system (GLL & GGA @ 4800 baud). The positioning system is calibrated daily utilizing the side scan sonar (refer to the Calibration section of the Side Scan Sonar SOP for details), thus it is reasonable to assume that the field calibration is valid for both sonar collection systems.

In addition, a sound velocity profile will be conducted once a week. The average will be computed from the profile and used as the speed of sound input for the collection software. Onyx-SS will use a Smart SV sound velocity profiler manufactured by Applied Geomechanics for creating the velocity profile.

Survey Setup:

Water depth, current, and site configuration will be reviewed prior to deployment of the sonar. Upon review, a pre-designed survey track-line plan (running with the river flow) will be entered into the HyPack navigation software. The trackline plan (identical for both side scan and sub-bottom work) will position parallel tracklines 120 feet apart from each other within the area to be surveyed. The tracklines will extend the full width of the river for complete coverage of the survey area.

The sub-bottom profiling sonar is typically deployed to a depth that minimizes turbulence around the fish and maintains it at a near constant height/direction through the water. When survey speeds are held between 3 and 5 knots (in areas with greater than 5 feet of water depth), the sonar will be deployed to a depth of 3 feet. In extremely shallow areas, the vessel speed will be reduced (2 to 3 knots) as well as the fish height (2 feet of water depth). We anticipate the fish layback to vary no more than 1 to 2 feet, which will be updated within the software to reflect our survey speed.

Survey geodesy for the HyPack navigation software will be set in State Plane (NAD83) Wisconsin Central (4802) with the vertical datum of NAVD 88. However, the Edgetech X-Star sub-bottom profiling sonar software only collects data in geographic coordinates, so all sonar images will the geo-referenced in latitude and longitude (DDM).

Daily Survey Procedure

The sub-bottom profiling survey crew will consist of two crewmembers (1 vessel operator and 1 sonar technician), with one of the crewmembers being a lead surveyor within the Onyx-SS hydrographic survey group. Prior to launching the vessel, the survey crew will setup the RTK positioning system over one of the pre-surveyed benchmarks within the area to be surveyed that day (refer to the RTK Positioning SOP document for details on this procedure). The sonar technician will then connected the umbilical to the sub-bottom tow fish, power-up the topside sonar PC, and activate the Edgetech X-Star profiling software. During the start-up process, the operator will hear an audible test "chirp" from the fish indicating that the system is communicating properly (refer to the Edgetech X-Star Manual for details on program operation).

Once the operation of the sub-bottom profiling system is confirmed, the survey vessel will be launched and the sonar technician will power-up the HyPack Max 2.11c navigation software (refer to the e-document "HyPack Max Operation Manual" for details on program operation). The survey trackline plan for the days survey activities will be loaded and displayed for the vessel operator to follow. The vessel operator will navigate the vessel to the control structure to confirm the side scan sonar accuracy (refer to the Side Scan Sonar SOP). Along the way, the sonar technician will deploy the sub-bottom tow fish and set the sonar gains to provide satisfactory image quality. Unlike other sonar systems, the image displayed by the sub-bottom profiling software is independent from the image recorded. Thus, images can be improved during data processing to provide the best possible resolution for making thickness determinations.

Once the review is complete and satisfactory, the survey will be conducted according to the track-line plan. Each trackline that is run will be given a unique number and saved to data tape as they are collected. The software saves individual survey image files and navigation files to data tape for conversion to CD at a later date.

All frequencies, configuration settings, and survey progress with the area track-line plan will be recorded on the daily survey log. A copy of this log showing the information recorded each day is included with this SOP.

MSCL General Description

The GEOTEK Multi-Sensor Core Logger (MSCL) is a commercial version of the core logger developed for the Deep Sea Drilling Projecdt and Ocean Drilling Program shipboard physical properties laboratories. The MSCL enables a number of non-destructive geophysical measurements to be made on un-split (whole round) sediment cores encased in cylindrical plastic core liners. The methodology used to calibrate and operate the device is well established, as are the limitations of the device. Obtaining accurate results from the MSCL is largely dependent upon the quality of the calibrations performed and the quality of the cores being logged. An overview of the complete apparatus is shown in Figure 1.

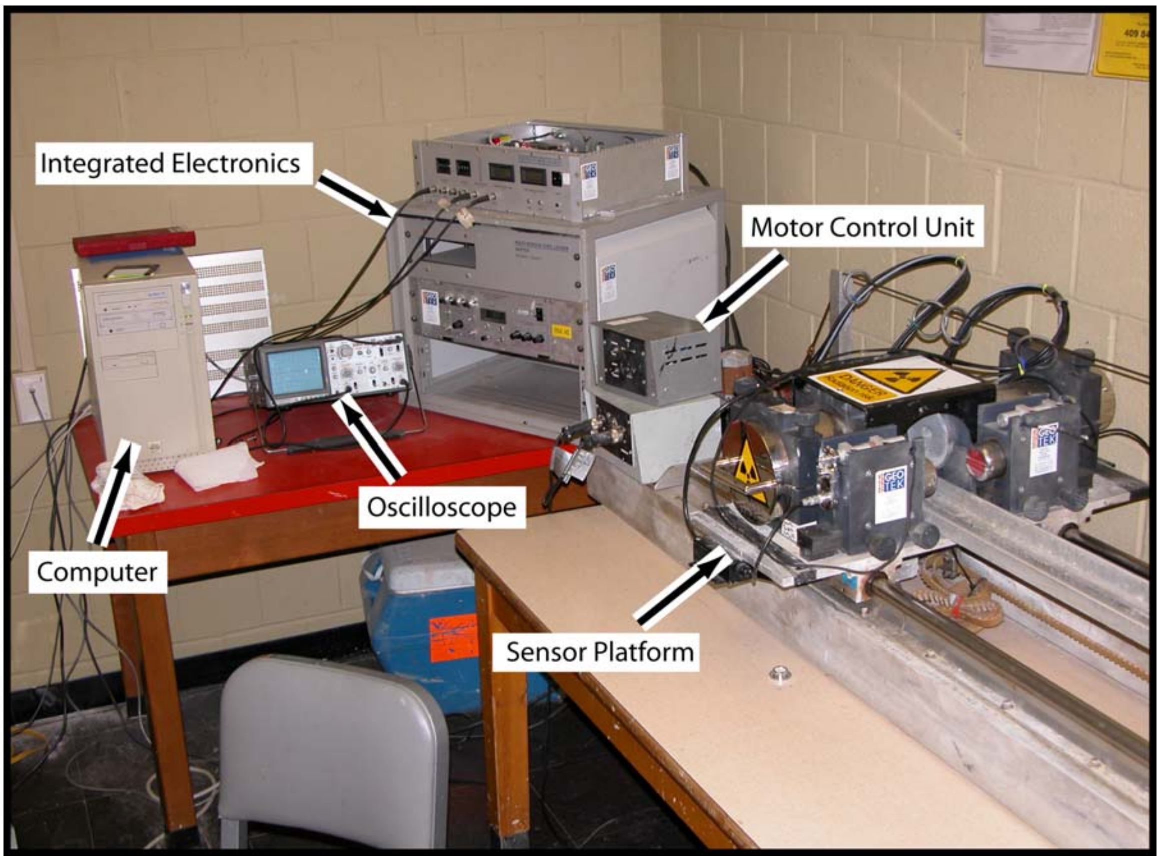

Figure 1. Overview of the main components of the GEOTEK Multi-Sensor Core Logger.

The primary measurement sensors used on the MSCL are as follows (see Figure 2):

- **Acoustic Transducers** - measure the velocity of 500kHz compressional waves (P-waves) in the core.
- **Gamma Ray Source and Detector** - measure the attenuation of gamma rays through the core to provide density/porosity values.

- **Displacement Transducers** – measure the diameter of the core and enable calculation of compressional wave velocity and density by accounting for changes in the core diameter.
- **Platinum Resistance Thermometer (PRT)** (not shown) – measures temperature during the logging process, which is particularly important for compressional wave velocity calculation.

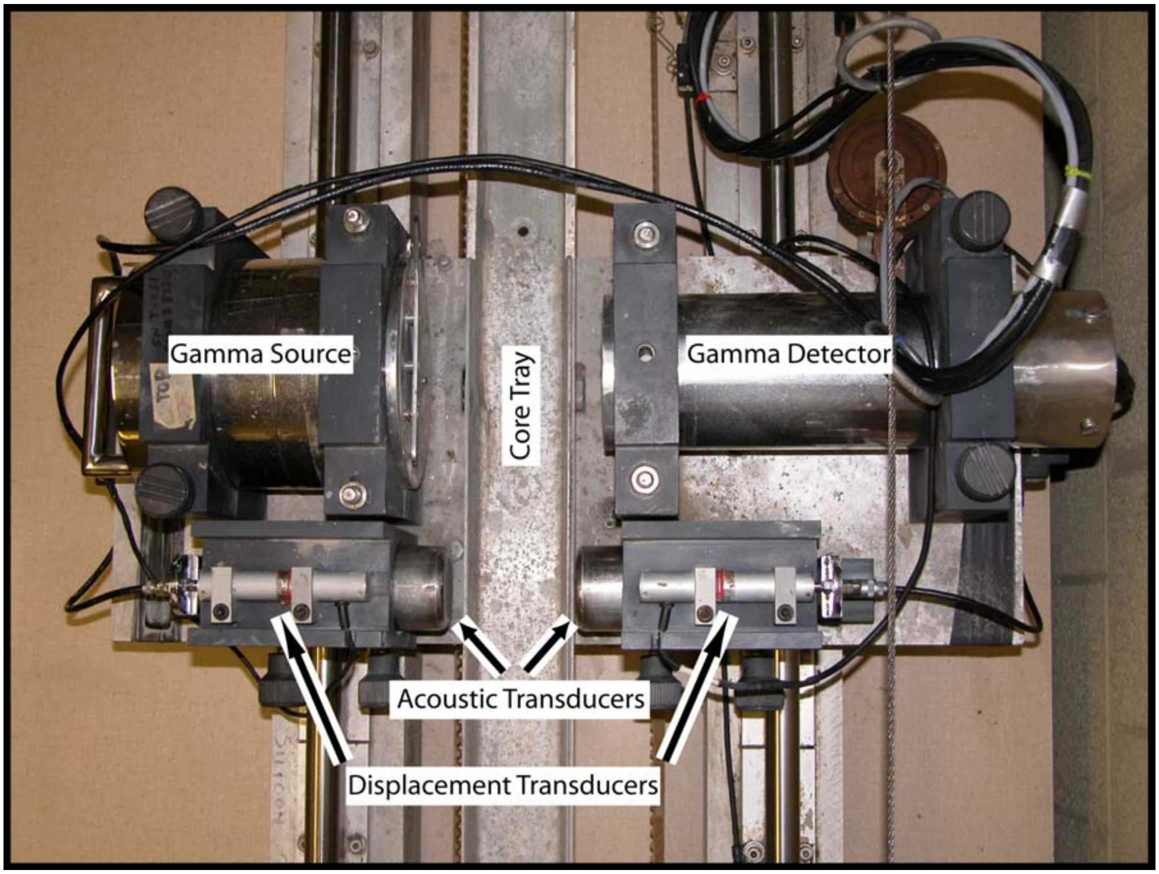

Figure 2. Top-down view of the MSCL sensor arrangement.

Operating Principles

Gamma Density

A gamma ray source and detector are mounted across the core on a sensor stand that aligns them with the center of the core. A narrow beam of gamma rays is emitted from a Cesium-137 source with energies principally at 0.662 MeV. These photons pass through the core and are detected on the other side. At this energy level the primary mechanism for the attenuation of gamma rays is by Compton scattering. The incident photons are scattered by the electrons in the core with a partial energy loss. The attenuation, therefore, is directly related to the number of electrons in the gamma ray beam. By measuring the number of unscattered gamma photons that pass through the core unattenuated the density of the core material can be determined. To differentiate between scattered and unscattered photons the gamma detector system only counts those photons that have the same principal energy of the source. To do this a counting window is set which spans the region of interest around 0.662 MeV.

The determination of bulk density using a gamma logger is based upon the well-established relationship between electron density and bulk density (e.g. Boyce, 1976; Evans, 1965; Evans and Cotteral, 1970). A Cesium-137 source is used to produce a collimated beam of gamma rays that is directed through the core to the gamma detector. The electron density of sediment, which closely approximates the sediment bulk density, is a function of the ratio of the source intensity through air to the source intensity through the core.

P-Wave Velocity

A short P-wave pulse is produced at the transmitter. This pulse propagates through the core and is detected by the receiver. Pulse timing circuitry is used to measure the travel time of the pulse with a resolution of 50 ns. The distance traveled is measured as the outside core diameter with an accuracy of 0.1 mm. The path length is corrected for the average thickness of the liner so that only the path through the sediment is used in the calculation of velocity. The measured travel time must be similarly corrected for the delay associated with the travel time through the electronics and the liner. The relationship between temperature and velocity of seawater is used to correct all calculated velocities to 23 °C. After suitable calibration procedures have been followed (see Calibration section) the P-wave velocity can be calculated with a resolution of about 1.5 m/s. The accuracy of the measurements will largely depend on any variations in liner wall thickness. However, experience has shown that an absolute accuracy of ± 3 m/s is normally achievable with some care. A complete discussion of the theory of operation and calculations can be found in Schultheiss and McPhail (1989).

Core Thickness

The thickness or diameter of the core is measured as the distance between the active faces of the two acoustic transducers (AT). This is achieved by mounting a rectilinear displacement transducer (DT) on each of the AT mountings. Each DT is coupled to the moving AT via a bracket at the rear end of each transducer. In this way each DT precisely follows the movement of each AT. In practice the core thickness is measured with reference to a known thickness and it is the deviation from that reference thickness that is recorded. The 2 DTs are wired together in such a way that equal movements in the same direction produce no change in reading. Only real changes in total offset are recorded. The total travel of each transducer is only 20 mm, hence they must be mounted so that the travel matches that of the PWT.

Temperature

A standard PRT (platinum resistance thermometer) probe is used to measure temperature. The probe is connected to a long flying lead that can be inserted into a beaker of water or sediment near the MSCL. Prior to logging, cores are equilibrated to room temperature; therefore, any change in the recorded beaker temperature is assumed to be matched by the core sections themselves. It is most important for accurate velocity measurements in sediments because velocity changes by approximately 3 ms-1°C-1.

MSCL Methods

Calibration

Calibration of the MSCL is performed prior to each logging session and every 4 hours thereafter. To calibrate the core logger, a section of the same type of liner used for the sediment cores is used. A pure aluminum calibration piece composed of 5 different diameter sections is placed within the liner such that the cross-sections of the liner and calibration piece align (Figure 3). The liner is then filled with distilled water and sealed at both ends. Special internal end caps with o-rings are used to prevent misaligning the center of the calibration piece with the gamma ray beam that would occur with end caps that ride over the exterior of the liner. Consequently, the calibration core simulates a water saturated sediment core with the added benefit of knowing the exact water/aluminum ratios, so that a calibration gamma density to bulk density equation can be determined. Likewise, the empty water section of the core can be used to calibrate the P-wave velocity based on the known velocity of sound in water at a specific temperature.

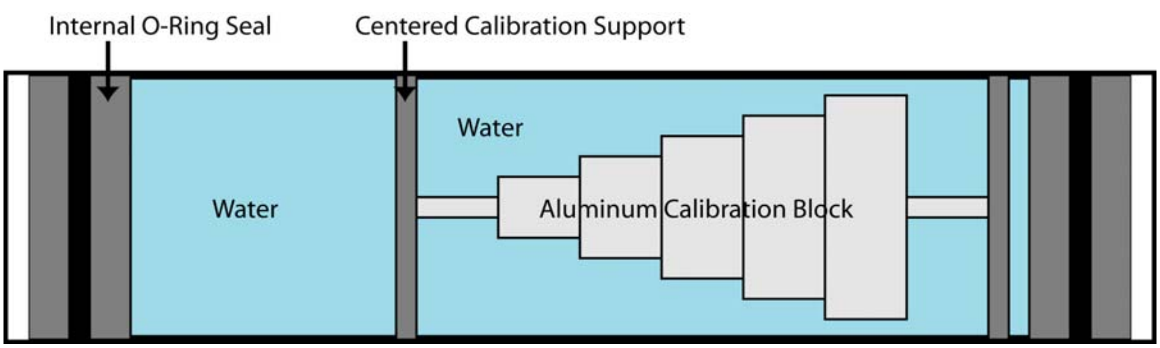

Figure 3. Lengthwise cross-section of a calibration core.

Compressional wave velocity calibration is performed by centering the acoustic transducers on the water section of the calibration core. Then measurements are taken of core diameter displacement, travel time, and temperature. The water velocity is calculated for the calibration core and compared to UNESCO #44 distilled water velocity at the same temperature from Fofonoff and Millard (1983). The difference in the measured and calculated velocities is the travel time offset (TTO) caused by delays introduced by the electronics.

Bulk density calibration is performed by measuring the total number of gamma counts at each of the aluminum calibration block locations as well as the pure water region. Three measurements are taken and averaged at each point. The aluminum density is assumed to be 2.71 g/cm^3 and that of distilled water to be 1.00 g/cm^3. Since the individual densities are known a bulk density can be calculated for each aluminum diameter location. Thus, an empirical relationship for bulk density is established by plotting bulk density*diameter against the natural log of the counts per second (Figure 4).

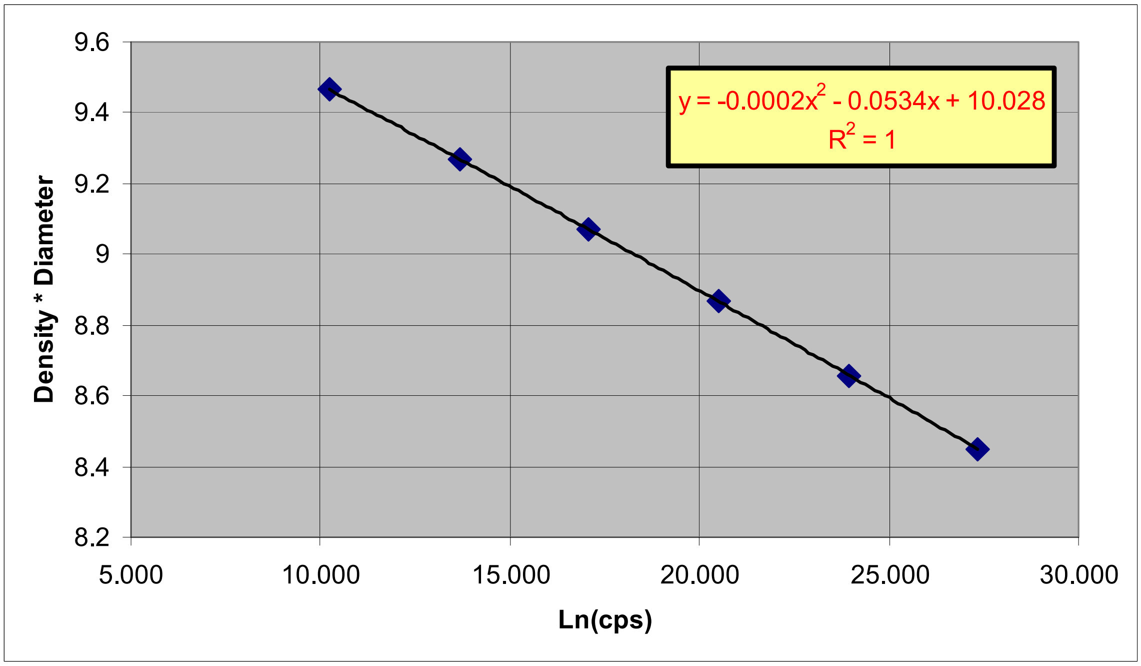

Figure 4. Typical second degree polynomial fit to gamma calibration points measured through each aluminum diameter location and through pure water.

Core Logging

Prior to logging cores they are placed in the logging area and equilibrated to room temperature for a minimum of 12 hours. The end caps are removed from each section prior to logging. Internal blocks are used in the core ends to keep high water content sediments in the liner during logging. After following the calibration procedures listed above, each core is then logged one section at a time, beginning with the topmost section. Logging consists of placing a known diameter reference section between the acoustic transducers and establishing that displacement as zero. All displacement data is based on the difference from the known reference core thickness (RCT) value. The sensor platform is then moved to the reference point at the bottom of the first section and recorded by the MSCL software. The software bases all distance measurements on the difference in position from the reference point. The software is then used to move the sensor platform to the top of the first section and automated logging begins. At the end of each section a new section is placed in the logger and the sensor platform is moved to the top of the section. This process is repeated until all sections are logged.

During logging the core liner is continually wetted with water to maintain optimum acoustic contact with the P-wave transducers. Additionally, the oscilloscope is monitored to identify areas of poor acoustic contact and measurement of the travel time within the proper location of the received waveform.

Calculations

The following are the calculations used by the MSCL software to calculate the various physical properties.

Sediment Thickness

$x = x_{rc} - x_w + x_{cd}/10$

x	=	sediment thickness (cm)
x_{rc}	=	reference core thickness (cm)
x_w	=	total wall thickness (cm)
x_{cd}	=	core thickness deviation (mm)

The RCT is the measured diameter of a circular reference standard. The x_w is determined by taking the average of a minimum of 20 measurements on a sample piece of core liner. The x_{cd} is recorded by the MSCL.

P-Wave Amplitude

$A = \mathrm{a} * A_m + \mathrm{b}$

A	=	P-wave amplitude
A_m	=	measured P-wave amplitude
a	=	constant
b	=	constant

The P-wave amplitude calculation simply applies a linear scaling factor if necessary to the A_m recorded by the MSCL. Normal procedure uses a=1 and b=0.

Corrected P-Wave Velocity

$v_{corr} = v * v_{fac}$

$v = (10^4 * x) / t$

$t = t_{tot} - t_{po}$

v_{corr}	=	corrected P-wave velocity (m/s)
v	=	P-wave velocity at measured temperature (m/s)
v_{fac}	=	(water velocity in situ) / (water velocity in lab)
x	=	sediment thickness (cm)
t	=	sediment travel time (µsec)
t_{po}	=	P-wave travel time offset (µsec)
t_{tot}	=	total travel time (µsec)

The v_{corr} corrects to lab conditions and with normal procedure using a salinity of 35 °%, a temperature of 23 °C, and a depth of 0 m. In the above equations t_{tot} is measured by the MSCL and t_{po} is calculated during the calibration procedures as described above.

Gamma Density

$$\ln(\mu_g) = a\,(\rho_b x)^2 + b(\rho_b\, x) + c$$

ρ_b	=	gamma bulk density (g/cm^3)
x	=	sediment thickness (cm)
μ_g	=	gamma attenuation (counts/s)
A	=	constant
B	=	constant
C	=	constant

Gamma bulk density is determined by solving the above equation for ρ_b and taking the positive root if A is not zero. Gamma attenuation is measured by the MSCL and the coefficients A, B and C are calculated during calibration as described above.

Impedance

$$Z = v_{corr} * \rho_b$$

Z	=	acoustic impedance
v_{corr}	=	corrected P-wave velocity (m/s)
ρ_b	=	gamma bulk density (g/cm^3)

Impedance is simply the product of velocity and density.

Porosity

$$\varphi = (\rho_g - \rho_b) / (\rho_g - \rho_w)$$

φ	=	fractional porosity
ρ_b	=	gamma density (g/cm^3)
ρ_g	=	mineral grain density (g/cm^3)
ρ_w	=	water density (g/cm^3)

Porosity is calculated from ρ_b based on an assumed ρ_g of 2.68 g/cm^3 and ρ_w of 1.025 g/cm^3. The porosity calculation is based on the assumption of a completely water saturated core. Another way of looking at the porosity is simply as a ratio of the volume of the pore space (voids) to the total volume of sediment.

$$\varphi = V_v / V_t$$

V_v	=	volume of the voids
V_t	=	total sediment volume

Void Ratio

$e = V_v / V_s$

e	=	void ratio
V_v	=	volume of the voids (pore space)
V_s	=	volume of the solids

Water Content

$w = M_w / M_s * 100$

w	=	water content (%)
M_w	=	mass of water (g)
M_s	=	mass of solids (g)

Since water content is simply a ratio of the water component of bulk sediments to the dry solid component of bulk sediment, the value may often exceed 100%.

Porosity, Void Ratio, and Water Content Relationships

Given the definitions above, the following relationships hold for porosity, void ratio and water content:

$\varphi = e / (1 + e)$

$e = \varphi / (1 - \varphi)$

$w = (\rho_w / \rho_g) * e * 100$

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Onyx Special Services, Inc.
Hydrographic Standard Operations & Procedures

RTK VESSEL POSITIONING SYSTEM

Equipment Overview:

To achieve reliable accuracy within ±2-3 centimeters in the horizontal and vertical planes requires the use of a Real-time Kinematic (RTK) positioning system. The system combines DGPS satellite positioning with a land-based beacon set at a known location or benchmark. The land-based beacon is in constant communication with a mobile beacon (on the boat) via a radio link. The system is able to interpolate the mobile beacon's position by calculating a "solution" derived from the positions given by a number of satellites, the differential signal, the land-based beacon position, and the distance measured between the two beacons via their radio link.

The DGPS and RTK systems used for this project are a Trimble 4700 base unit in conjunction with a Trimble MS750 Rover Unit. The 4700 base unit is controlled with the Trimble TSC1 data logger which also serves as the benchmark point coordinate data input/storage device. The radio link between the two Trimble units is supplied by a Pacific Crest system; consisting of the PDL base transmitter and a TM32 mobile unit.

System Performance:

Because the link between the base unit and the mobile beacon must be maintained, there exists the possibility that "dead zones" will exist in the survey area (zones within the survey area where radio signal is lost). The HyPack navigation software will also be configured to activate a visual alarm to alert the operators when unacceptable accuracy conditions or dead zones are present. The three modes of RTK survey are: fix (accuracy ± 2 to 3 cm), float (accuracy ± 1 meter), and autonomous (accuracy ± 30 meters). HyPack will be configured to display the mode of RTK survey accuracy in real-time and alarm when no data is present. Moving the base unit may eliminate dead zones; however, if this does not remedy the situation, the client representative will be consulted and the area will be noted.

Field vertical positioning checks will be conducted by measuring water datum from a fixed reference gage before and after each survey day. The measurements will be recorded on the survey log and can be compared to the vertical output from the RTK system to verify accuracy. These checks will only be performed during bathymetric data collection (side scan sonar and sub-bottom sonar surveying do not provide accurate water depth information, thus the vertical positioning accuracy is not relevant).

Daily Procedure:

Prior to beginning the days survey activities, the RTK base station will be setup over one of the pre-surveyed benchmarks provided by the client. The selection of the benchmark will be determined by the area to be surveyed that day. Once setup, the base station benchmark position point will be entered (the position point is a preset point containing the vertical/horizontal position of the benchmark) into the TSC1 unit. Next, the operator will power on the base station (via the TSC1) and confirm that both are functioning properly (refer to the operations manuals for the TSC1 & 4700 units).

Onyx will perform two verification checks on the system once the base station is set and operating correctly. The first verification will involve the operator powering on the Trimble MS750 mobile unit, placing the mobile antenna over the base station benchmark, and checking/recording the output position. The output position from the mobile unit should match the benchmark position within 1 thousand of a second when functioning properly in RTK fix mode. The positioning/setup information for this verification will be recorded on the daily survey log.

The second verification on the system is to relocate the mobile unit to another adjacent benchmark and verify the mobile output in the same manor as was outlined for the base station position. As before, the mobile antenna will be held over the benchmark and its position output will be compared to the known position of the benchmark. This second verification will also be recorded on the daily survey log. At the end of the survey day, the second verification procedure will be repeated at the same benchmark used in the beginning of that day.

Onyx will have standard DGPS positioning available at all times on the vessel. Throughout the survey day, random checks can be made between the two positioning outputs to confirm their performance. If at any point in the survey the operator or client representative observes a difference of greater than 1 meter between the two systems, the survey will be halted and both systems will be checked for possible errors.

CHAIN-OF-CUSTODY PROCEDURES

1.0 PURPOSE

Chain-of-custody procedures are established to provide sample integrity. Sample custody protocols will be based on procedures as described in "NEIC Policies and Procedures", EPA-330/9-78-DD1-R, Revised June, 1985. This custody is in two parts: sample collection and laboratory analysis. A sample is under a person's custody if it meets the following requirements:

- It is in the person's possession;
- It is in the person's view, after being in the person's possession;
- It was in the person's possession and it was placed in a secured location; or
- It is in a designated secure area.

All samples submitted to a laboratory shall be accompanied by a properly completed Chain of Custody form.

2.0 FIELD SPECIFIC CUSTODY PROCEDURES

The sample packaging and shipment procedures summarized below will assure that the samples will arrive at the laboratory with the chain-of-custody intact.

Field procedures are as follows:

(a) The field sampler is personally responsible for the care and custody of the samples until they are transferred or properly dispatched. As few people as possible should handle the samples.

(b) All bottles should be tagged with sample numbers and locations.

(c) Sample tags should be filled out using waterproof ink for each sample.

(d) The Project Manager should review all field activities to determine whether proper custody procedures were followed during the field work and decide if additional samples are required.

Transfer of Custody and Shipment Procedures are as follows:

(a) Samples should be accompanied by a properly completed chain-of-custody form. The sample numbers, locations, media, time of collection, preservative and required analyses will be listed on the chain-of-custody form. When transferring the possession of samples, the individuals relinquishing and receiving will sign, date, and note the time on the record. This record documents transfer of custody of samples from the sampler to another person, to a mobile laboratory, to the permanent laboratory, or to/from a secure storage area.

(b) Samples will be properly packaged for shipment and dispatched to the appropriate laboratory for analysis with a separate signed custody record enclosed in each sample box or cooler. Shipping containers will be locked and/or secured with strapping tape in at least two locations for shipment to the laboratory.

(c) Whenever samples are split with a source or government agency, a separate Sample Receipt is prepared for those samples and marked to indicate with whom the samples are being split. The person relinquishing the samples to the facility or agency should request the representative's signature acknowledging sample receipt. If the representative is unavailable or refuses, this is noted in the "Received By" space.

(d) All shipments will be accompanied by the Chain-of-Custody record identifying the contents. The original record will accompany the shipment, and the pink and yellow copies will be retained by the sampler for returning to the sample office.

(e) If the samples are sent by common carrier, a bill of lading should be used. Receipts of bills of lading will be retained as part of the permanent documentation. If sent by mail, the package will be registered with return receipt requested. Commercial carriers are not required to sign off on the custody form as long as the custody forms are sealed inside the sample cooler.

The Chain of Custody records will be kept with the analytical laboratory reports in the project master file.

CHAIN OF CUSTODY RECORD

Natural Resource Technology
N R T

Sample Collectors(s)/Signature(s)	**NATURAL RESOURCE TECHNOLOGY, INC. PEWAUKEE, WISCONSIN**	Laboratory Samples are Being Submitted To: ____ Quote Number/Addendum Number __________________ Attached: YES __ NO __

Site Name: ____ Site Address: ____ ____	Send Report To: Project Manager: ______________________ Project Number: ___________ Natural Resource Technology, Inc. 23713 W. Paul Road Task Number: _____________ Pewaukee, WI 53072 Telephone (262) 523-9000 Fax (262) 523-9001	Temperature of temperature blank ___________ If sample(s) were received on ice and there was ice remaining, you may report the temperature as "received on ice". If all of the ice was melted, the temperature of the melt may be substituted for a temperature blank.

I hereby certify that I received, properly handled, and maintained custody of these samples as noted below:

Relinquished By (Signature)	Date/Time	Received By (Signature)	Date/Time
Relinquished By (Signature)	Date/Time	Received By (Signature)	Date/Time
Relinquished By (Signature)	Date/Time	Received By (Signature)	Date/Time

Analytical Method / Numbers

Lab Use Only

Field ID Number	Date Collected	Time Collected	Sample		Location / Description	PID Reading	Field Comments	Preserv. Type	# of Cont.								Lab ID Number	Sample Conditions @ Laboratory
			Media	Device														

SPECIAL INSTRUCTIONS	Laboratory shall retain samples for 30 days after issuing Analytical report unless indicated otherwise below: ___ Return ___ Other ________________________

SAMPLE CONTROL LOG

Natural
Resource
Technology

Project Name: ______________________________ Laboratory: ______________________________

Project and Task No.: ______________________________ Page ______ of ______

Sampling Date	Sampling Time	Sample Number ID	Sample Depth Interval (WTM NAD 83/91)	C.O.C. Number	Analysis Requested	Turnaround Time, Sample Location, Handling Notes, Chain-of-Custody remarks, etc. (Duplicate/blank info, etc.)	Date Sent to Lab	Date Results Due

Appendix B

Phased Sampling Approach

Sample size, Spatial Allocation of Samples and Statistical Methods for Detection of the Boundary of 1 ppm PCB Concentration in Sediment of the Lower Fox River, Wisconsin

Nayak Polissar, Ph.D., Derek Stanford, Ph.D., Blazej Neradilek

June 30, 2003

SECTION 1 -- INTRODUCTION

1.1 Purpose

The purpose of this document is to present a sampling plan and method of statistical analysis for sediment samples obtained from the Lower Fox River in Wisconsin. The sampling plan and the plan for analysis of the resulting sample PCB concentrations can be used to determine sediment volumes in the Lower Fox River that have a PCB concentration exceeding 1 ppm.

At the conclusion of the sampling and remediation process, a desirable statement to be made is that we are confident that a sample taken outside of the remediation area would not encounter a concentration over 1 ppm, with a confidence level of, for example, 95 percent. Appropriately addressing measurement uncertainty and the uncertainty of estimated concentrations lying between sample points will allow us to make such a statement. Thus, this document addresses statistical uncertainty and its implications.

1.2 Overview

This report addresses the inherently difficult task of minimizing sampling effort to obtain maximum information. It is obvious that an extremely dense sampling of sediment cores from the Lower Fox River would yield all the information needed to identify sediment volumes that are over 1 ppm. However, such a dense sampling and the enormous sampling effort associated with it is neither a necessary nor a good use of resources. A much more sparse sampling, carried out in two phases (see next Section, "REASONS FOR TWO PHASES OF SAMPLING") can supply the information needed.

By use of two-phase sampling, described in the next Section, an initial map of PCB concentrations is obtained. The first phase proposed below also provides important information on how precisely concentrations can be estimated between sample points. The sampling in the second phase can then be targeted at locations where new sampling can reduce uncertainty and, for example, very likely increase the area that can confidently be stated to be under 1 ppm PCB concentration. This second phase will more accurately define the specific boundary of the sediment volumes that will need remediation.

Bringing uncertainty into the picture and attempting to control that uncertainty is an important feature of the sampling design and analysis of sample results. While there are many methods for taking sample information and estimating concentration of PCB's between sample points, it is essential to attach some measure of the confidence we have in those between-sample points. If only the area that has an <u>expected</u> concentration of 1 ppm or more is remediated, then substantial areas lying outside of this boundary are very likely to have concentrations over 1 ppm, masked by the uncertainty of the estimation process, which has incorrectly labeled them as an area with less than 1 ppm concentration.

Indeed, it is true that any estimation method is imperfect and that the true concentration at points in between samples is likely to differ, perhaps substantially, between the estimated value and the true value which would be observed if we went in, after the fact, and sampled that specific point. Thus, dealing with remediation issues is a process of bounding the uncertainty yet not spending all the effort on that bounding process.

In addition to dealing with uncertainty, another major effort of the report is to find the extent to which the sediment layers "work together". That is, it will be helpful to know whether the sediment is "well behaved" in the sense that the lower sediment layers have areas over 1 ppm concentration that are geographically outlined within the 1 ppm boundary outline of upper layers. We refer to this issue as "concentricity". If the sediment layers are "well behaved", it makes the sample designation much simpler and more economical.

Finally, there is the issue of deciding <u>where</u> to sample in Phase II, given the analyses results from the Phase I sampling. Our strategy here is to sample more intensively in those areas where sampling can reduce the sediment volume to be remediated. For example, if a particular area has a concentration somewhat below 1 ppm, but the upper bound in our confidence statement includes concentrations over 1 ppm, then it will pay-off to sample at or near such a point, because it is possible and even likely that we can reduce the uncertainty in the estimated concentration in this area to the point where our 95 percent confidence statement will eliminate values above 1 ppm.

A single report cannot cover all statistical aspects of the sampling effort, and the Discussion Section is an important one to read. There we consider obstacles and opportunities in the road ahead. In particular, some of the findings from the data analyses (historic data only) of OU1 (Little Lake Butte des Mortes) may need to be modified for the other reaches. Because the other reaches are less like a lake and more like a true river, these other reaches are likely to have features relevant to sampling that are different from those found in Little Lake Butte des Mortes.

As an editorial note, figures and tables are numbered according to the section in which they occur. Thus, Figure 7.1 can be found in section 7.

SECTION 2.0 – REASONS FOR TWO PHASES OF SAMPLING

The two-phase sampling plan provides an opportunity to direct sampling effort at areas where it will pay off. The first phase includes fairly sparse sampling (anticipated now at one per acre). We showed in an earlier report to Retec that the main challenge in extrapolating PCB concentration from sample points to nearby (non-sampled) points was the uncertainty (variance) of the extrapolated value. (Reference: Polissar N, Stanford D "Sampling Sediment in the Lower Fox River: How Many Samples?" Report from the Mountain Whisper Light to Retec Corporation, March 16, 2003.) Even with a grid of one sample per acre up to several samples per acre, there is still considerable uncertainty about the concentration lying in between sample points, because short range variability of predicted concentrations is large. Therefore, the proposed first phase of sampling includes clusters of samples around particular nodes of the triangle sampling lattice. These clusters of samples, combined with the more open triangular sampling grid, will provide good estimates of the variance of predicted concentrations at any distance—short or long—from a sample point. And, the first phase of sampling—fairly sparse—will show the “lay of the land” in the form of a map of estimated concentrations. From this map, the areas with estimated concentrations that are below 1 ppm but with confidence intervals for concentration that reach above 1 ppm can be identified. These areas are prime candidates for additional sampling in phase II, because new samples spotted in these areas will calm the uncertainty and very likely bring confidence intervals, for some of these regions, below 1 ppm.

SECTION 3.0 -- NEED FOR CLUSTERS OF SAMPLES

The need for clusters of samples arises from the method—kriging—used to assign estimated concentrations for non-sampled points falling between sample locations. Thus, we provide an explanation of this important methodology.

3.1 Background: Kriging Methods

In order to analyze the PCB concentrations in the area of interest, we use an approach called “kriging”. This approach uses point samples taken in a region and provides both an estimate of the PCB concentration (the mean) and an estimate of the standard error (SE) of the estimate for any point in the region. The SE is important because it allows us to form confidence intervals around the mean estimate. The kriging method uses a “variogram” to model the spatial correlation (or covariance) in the data. The variogram can be thought of as a function (or a plot) of variance versus distance. The plot or function is proportional to the variance between concentrations from two samples collected at a specified distance from each other. The distance is the independent variable (X-axis of a plot) and the variance is the dependent variable (Y-axis of the plot). Typically, as the distance between the samples increases, the variance increases, up to a point, and then levels off for large distances. This makes sense, because when samples are close together, the variance of their concentration is likely to be smaller than when they are far apart. When they are very far apart, their concentrations are essentially uncorrelated, and the variance between the two concentrations levels off, corresponding to this limiting zero correlation. Usually, a mathematical function is fit to the variogram plot. Examples of variogram plots are included in Section 7. The kriging algorithm proceeds by estimating the parameters of the variogram from the data, and then computing the kriging estimates of the mean concentration and SE at a new (user-specified) location. The new estimate uses the variogram as a way to weight concentrations from all other samples in the dataset in order to come up with the estimate for the new location. The weighting applied to an observed concentration from another location is inversely related to the variance for the distance between the other location and the new, user-specified location. The variance (and inverse weighting) is taken from the variogram function. Intuitively and practically, the observed concentrations from samples close to the new location receive more weight than remote samples. The kriging estimation process also supplies an SE value for the estimated concentration (again using the variogram). A confidence interval for the estimate can be calculated using the SE of the estimate.

The key parameters involved in a variogram are the “nugget”, “sill”, and “range”. The sill represents the variance between samples taken at a large (“infinite”) distance apart; that is, the variance without the effect of any spatial correlation. The sill defines the upper limit of the variance. The nugget represents the variance of samples taken at zero distance apart; this can be thought of as the sampling replication variance. Practically speaking, two samples can not be taken from exactly the same location, so the nugget can be thought of as the variance between samples taken very close together. The nugget effect is important, because it defines the minimal level of uncertainty for concentrations in areas not sampled. Thus, the nugget effect figures prominently in sample size planning, and it is important to have a sufficient number of closely spaced samples in the first phase of sampling in order to accurately determine the short-range uncertainty; i.e. the nugget effect. It is a lower bound on the variance. The variance between samples at any distance is thus bounded below by the nugget and above by the sill. The range is the parameter which specifies the distance over which the variance between samples increases from the nugget value to the sill value. Beyond the range distance (e.g., 400 meters), the variance between samples levels off to a constant value in the variogram and kriging model.

We are using an exponential variogram model. This model fits reasonably well to summarize the observed variogram plot. The equation for the exponential model is given by

$$\mathrm{V}(D) = \mathrm{Nugget} + \mathrm{Sill}(1 - e^{-D/\mathrm{Range}})$$

where V(D) is the variogram value (proportional to the conventionally calculated variance) at distance D between two samples. An example of a variogram is displayed in Figure 7.1, where “gamma” on the Y-axis denotes the variogram value at the distance given on the X-axis. The variogram value at a particular distance is proportional to the variance between samples taken at that distance apart. The variogram plot is “binned”: distance bins are formed and then the variances are pooled (averaged) for all pairs points whose distance falls into the bin. Bins might be 0-20 feet, 20-40 feet, etc.

In order to accurately estimate the variogram, sample points are needed at a variety of distances from each other. In particular, the nugget effect requires samples at small distances. A regular sampling grid (such as the triangular lattice proposed for the Fox River) provides only certain fixed distances between sample points, with a rather large minimum distance. Thus, there is a need for occasional “clusters” of samples—locations in the sampling grid where several additional samples are taken in a small region. We have designed an example of a cluster configuration, which then provides necessary information over a variety of relatively small distances (see Section 4).

Once we have plotted the variogram and fitted the variogram model, we proceed with the kriging operation, which produces estimates of the mean and SE at any desired set of new points. We can calculate a two-sided 95 percent confidence interval for the PCB concentration at any new point by using the equation

$$\text{Confidence Interval} = \text{Mean} \pm 1.96(\text{SE})$$

where the Mean and SE values are the kriging estimates. For other confidence levels, the appropriate standard normal quantile would be used in place of 1.96 (e.g., 2.58 for a two-sided 99 percent confidence interval, or 1.64 for a two-sided 90 percent confidence interval). When we form the 95 percent confidence interval, we are making the statement that we are 95 percent confident that the interval includes the true concentration at the specified point.

For a given remediation threshold value, such as 1 ppm (= 1000 ppb) we can use confidence intervals to determine which regions are clearly above or clearly below the threshold. For a particular region, if the lower end of the confidence interval is above the threshold, then we are quite confident that the region (at that depth) should be remediated. If the upper end of the confidence interval is below the threshold, then we are confident that the region need not be remediated.

Section 4: Cluster configuration:

In order to ensure that there are a variety of interpoint distances between sample points, especially at short range, we add some small clusters of samples to the regular sampling grid. In this section, we describe an example of a cluster configuration which assumes a triangular sampling grid with 230 feet between sample points, based on an equilateral triangle. This grid provides roughly one sample per acre. This example can be extended to arbitrary triangular grid sizes simply by multiplying all derived distances by an adjustment factor which is the ratio of two quantities: a) the length of the side of the equilateral triangle, to b) 230 feet (in the example presented here). For other grid types, such as rectangular or hexagonal, the procedure described here for finding a cluster configuration can be used, but the final cluster configuration will be different. The configuration is determined by a simulation process that generates a large number of potential configurations and then selects the best configurations according to specified criteria.

In anticipation of the use of these data to estimate the variogram, we consider a set of distance bins which are 20 feet wide, i.e., 0 to 20 feet, 20 to 40 feet, etc. Our focus is on the first 11 bins (from 0 to 220 feet), since bins at longer distances will be addressed by the interaction of the cluster with points in the region-wide triangular grid. We begin by taking an arbitrary node in the triangular grid as the origin (coordinates 0,0). We then use a random process to generate configurations of nearby points for the cluster. The clusters were points in a rectangular lattice with a spacing of five feet between potential sample points. To compare the configurations and find the most suitable configuration, we compute the number of measurements which a particular configuration yields in each bin (for the first 11 bins only), and we assess the configurations using three criteria. First, we maximize the minimum number of measurements in any of the 11 bin. We use this rule to avoid bins which will have zero or very few measurements. For configurations which tie on this criterion, we seek uniformity in bin coverage by minimizing the ratio of the largest number of measurements per bin to the smallest number of measurements per bin. Lastly, configurations with points which are, on the average, closer to the origin are favored when there are ties for both of the first two criteria.

We used this algorithm to generate cluster configurations for a range of cluster sizes, from 4 to 7 points, arrayed near the chosen sample grid node. Table 4.1 shows the best configuration identified for each cluster size, along with the number of measurements per bin. At least 100,000 configurations were generated for each cluster size (4, 5, 6, or 7 points around the node) and the best configuration was chosen from among these. By using a sufficient number of these clusters, we insure that the variograms can be estimated with precision over all distances. In particular, Table 4.1 shows the minimum number of clusters needed to obtain at least 45 observations in each distance bin. Figure 4.1 shows each of the configurations on a background of the triangular sampling grid; the filled points are the cluster points, while the open points are the triangular grid points. One very striking result of this process is that these quite small cluster sizes (4-7 points) can generate the needed set of distances. The different cluster sizes will be appropriate for different economies and procedures of sampling. It would be desirable to use the smallest cluster size (4 points) and then take a large number of clusters. However, if the cluster sampling is too difficult or onerous, and the number of clusters must be minimized, then the large cluster sizes can be chosen.

Table 4.1 Cluster Configurations.

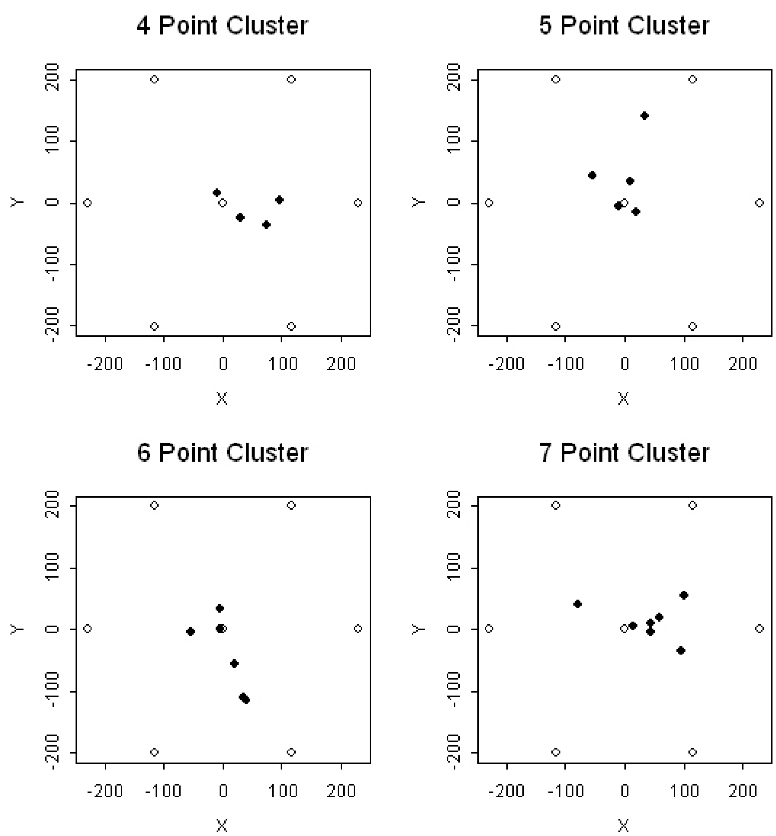
Cluster Size**	Number of Measurements per Bin											Clusters Needed*
	0-20	20-40	40-60	60-80	80-100	100-120	120-140	140-160	160-180	180-200	200-220	
4	1	1	3	1	3	1	1	1	1	2	3	45
5	1	3	2	3	2	1	1	3	2	2	3	45
6	2	2	4	3	2	3	4	3	4	2	4	23
7	3	3	5	4	5	3	3	4	3	5	5	15

* "Clusters Needed" indicates the minimum number of clusters required to obtain at least 45 observations in each bin.
**Coordinates of the clusters are as follows:
4 point cluster: (95,5),(30,-25),(-10,15),(75,-35);
5 point cluster (-10,-5),(35,140),(10,35),(20,-15),(-55,45) ;
6 point cluster(-5,35),(40,-115),(-55,-5),(20,-55),(35,-110),(-5,0) ;
7 point cluster (-80,40),(60,20),(15,5),(45,10),(100,55),(95,-35),(45,-5).

The cluster configuration can be rotated while maintaining its interpoint distance properties. If we regard the original configuration as being at an angle of 0 degrees, we can rotate it around the origin (the sampling grid point at which we started the cluster) to angles of 60, 120, 180, 240, and 300 degrees when we are using a triangular sampling grid. Different grid types (triangular, rectangular, hexagonal) will have different angles of symmetry. For example, a rectangular grid would accommodate rotations of 90, 180, and 270 degrees. By rotating the cluster configuration, we avoid potential systematic errors which might be introduced by always keeping the cluster in the same orientation, if there is "anisotropy" (see section 9.3). Anisotropy is the tendency to have a different variance/distance relationship in the variogram when, for example, one heads north compared to heading east. For example, heading north, one may find that the correlation between concentrations drops off much more rapidly than when one heads east.

To turn this cluster section into a specific sampling plan for Phase I, we recommend that, after the number of clusters has been specified, based on Table 4.1, that, initially, the clusters be allocated systematically across the nodes. That is, in the triangular sampling lattice, the nodes can be number sequentially by a path through the lattice that includes every node. Then, if there are, for example, 1000 numbered nodes, and we need 45 clusters (about one per 22 nodes), then, with a random start between 1 and 22, we take every 22nd node. Once these nodes are chosen, the estimated concentrations at the nodes (from kriging of the historic data) should be complied in a histogram to check that concentrations around 1 ppm are well-represented, with minimal representation of estimated concentrations that are very large (say, above 50 ppm) or very small (say, below 0.1 ppm). The location of the selected cluster nodes should be manually adjusted to ensure such representation. In addition, the clusters should be rotated form node to node so that the orientations of 0, 60, 120, 180, 240, and 300 degrees are approximately equally represented among the nodes.

Figure 4.1. Cluster configurations to aid in estimation of the variogram.



SECTION 5.0 – DEPTH AND "CONCENTRICITY"

The 1 ppm boundary for remediation involves not only horizontal location within sediment but depth within the sediment, as well. Accepted methods which can combine the observations across different depths in a kriging analysis to yield reasonably accurate concentrations estimates have not yet been developed for 3-dimensional spatial distributions as complicated as those found in this setting. Thus, we recommend that each depth stratum be addressed separately within each reach. After phase I sampling, the regions requiring additional sampling will then be combined across depth using a "cookie cutter" approach to ensure that all areas above 1 ppm are addressed. The cookie cutter approach uses a hypothetical cookie cutter on the map to outline the area to be remediated at each depth. The total area to be remediated is then the outer boundary of the combination of cookie cutter boundaries across all of the depths. However, the depth to which remediation is carried out will vary across the total area, according to the greatest depth at which target sediment (above 1 ppm) occurs at any given location.

As noted in our introduction, it will be helpful to know whether the sediment is "well behaved": do the lower sediment layers have areas over 1 ppm concentration that are geographically outlined within and somewhat concentric to the 1 ppm boundary outline of shallower layers? (We refer to this as "concentricity"). If the sediment layers are "well behaved" and concentric, it makes the designation of sample locations and depths much simpler. This issue is considered further in Section 7.

SECTION 6.0 – DATA FROM LITTLE LAKE BUTTE DES MORTS

As a prelude to the data analysis carried out for this document, we present the initial steps of preparing the data, defining depth strata, and other issues. Some of these issues will occur again in the future data analysis and are worth noting here. Some of them, such as specification of depth strata, are unique to the historic data.

6.1 Data Preparation

Data from 1,015 core samples from different locations and depths of Little Lake Butte des Mortes were supplied by Retec. Thirty-nine cases where excluded (leaving 976) because of missing information on northing or easting coordinates or depth of the core. (See Table 6.3 for a listing of these cases.)

6.2 Definition of Depth Strata

Cores were divided into five groups (depth strata) according to the depth of the middle point of the core. After quite extensive analysis of the cores' starting and ending depth and total length, we accepted a commonly used definition of the depth strata, which is summarized in Table 6.1. For example, the shallowest depth stratum starts at the surface and ends in the depth of 10 cm.

Table 6.1. Division of cores into five depth strata based on the depth of the core mid-depth

		Depth of the middle point of the core (cm.)	
Stratum		From	To
1	Shallowest	0	10
2		over 10	30
3		over 30	50
4		over 50	100
5	Deepest	over 100	

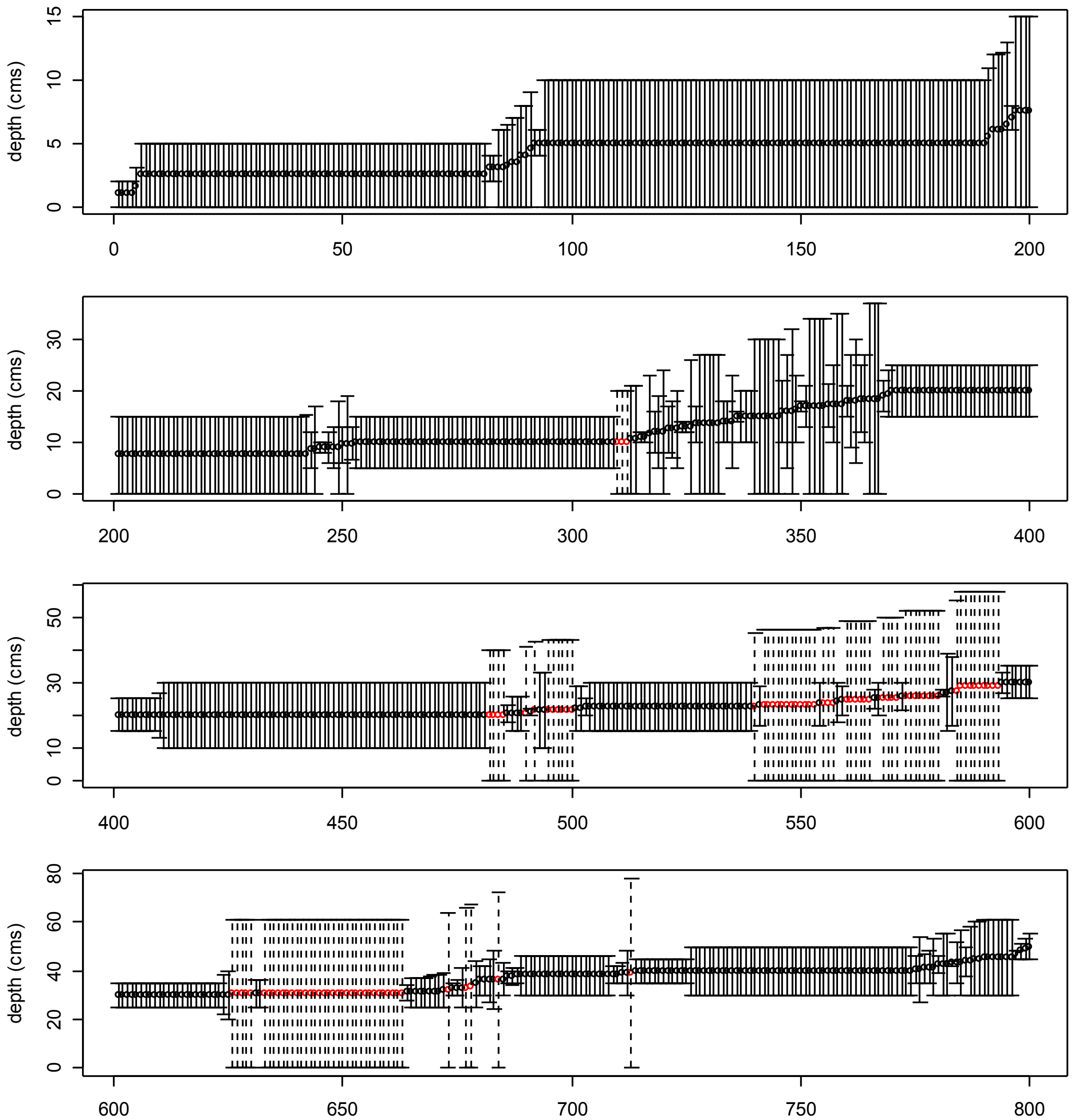
6.3 Exclusion of Cores Overlapping Several Depth Strata

Cores that were too long and, therefore, substantially overlapped two or more strata were excluded from the dataset. The criterion for exclusion of a core was that the length of the core (measured from its highest point to its lowest point) be equal to or exceed twice the length of the depth stratum it would be assigned to by the division mentioned above in Table 6.1. This expulsion is necessary to avoid cores that cross too many depth strata and can be considered to represent none in particular.

For example, if a core started in the depth 0 cm. and ended at depth 40cm., it would be included in the second stratum (because its midpoint is at 20 cm. depth). But, because its length is 40 cm., twice the length of stratum 2 (which has a width of 20 cm., from 10 cm. to 30 cm.), it is excluded from the analysis. This is, in fact, desirable because the core reaching from the depth 0 cm. to the 40 cm. covers the entire stratum 1, stratum 2 and half of the stratum 3 and, thus, provides information about several strata rather than about stratum 2, to which it would normally be assigned.

Thus, out of 976 cores, 100 cores were excluded due to core length. This exclusion is illustrated on Figure 6.1, which displays the range of the shallowest 800 cores, sorted by the depth of the midpoint. Each core is represented by a vertical bar starting at the shallowest depth and extending to the greatest depth. Vertical bars belonging to the cores that were excluded are drawn using a dashed line and a red midpoint. All of the 100 cores that were excluded are shown on this plot. The remaining 176 deeper cores were all included in the analysis and are not shown in the plot.

Figure 6.1. Depth ranges of the shallowest 800 samples, sorted by the depth of the midpoint of the sample (core segment). It shows all 100 excessively wide cores that were excluded (midpoint in red and dashed line). Note: each of the four plots has a different scale on the y-axis (depth).



6.4 Log-Transformed PCB Concentrations

PCB concentrations were transformed using logarithm with base 10. Prior to the log-transformation, PCB concentrations of the samples classified as non-detected were changed to half of their detection limit (59 cores). While we do not recommend this procedure for all analysis, the use of the historic data is illustrative rather than definitive, therefore these convenient transformations were used. Also, PCB concentrations equal to zero were changed to 0.1 ppb (99 cores), so that the logarithm could be calculated.

6.5 Pooling Log PCB Concentrations and Excluding Locations Outside of Little Lake Butte des Mortes

In cases where we had several core samples for the same location and depth stratum, the values of the log PCB concentration were averaged (mean) on the log scale. Finally, 18 data points representing 18 different combinations of location and depth outside of Little Lake Butte des Mortes (northing greater than 419600 m.) were excluded (see table 4).

The remaining 691 combinations of location and depth were used for the kriging analysis. Out of the 691 combinations, 224 were in depth stratum 1; 206 were in depth stratum 2; 127 were in depth stratum 3; 93 were in depth stratum 4; and 41 were in depth stratum 5.

6.6 Excluding Parts of Little Lake Butte des Mortes

Five parts of Little Lake Butte des Mortes were excluded from all analysis and displays. All five of them are inlets or outlets that do not have any data points inside their area or near them. The five areas are displayed on Figure 6.2. Each of the five areas was cut off by a chord with vertices located on the outline of the lake. The coordinates of the vertices are shown in Table 6.2.

Figure 6-2. Excluded parts of Little Lake Butte des Mortes

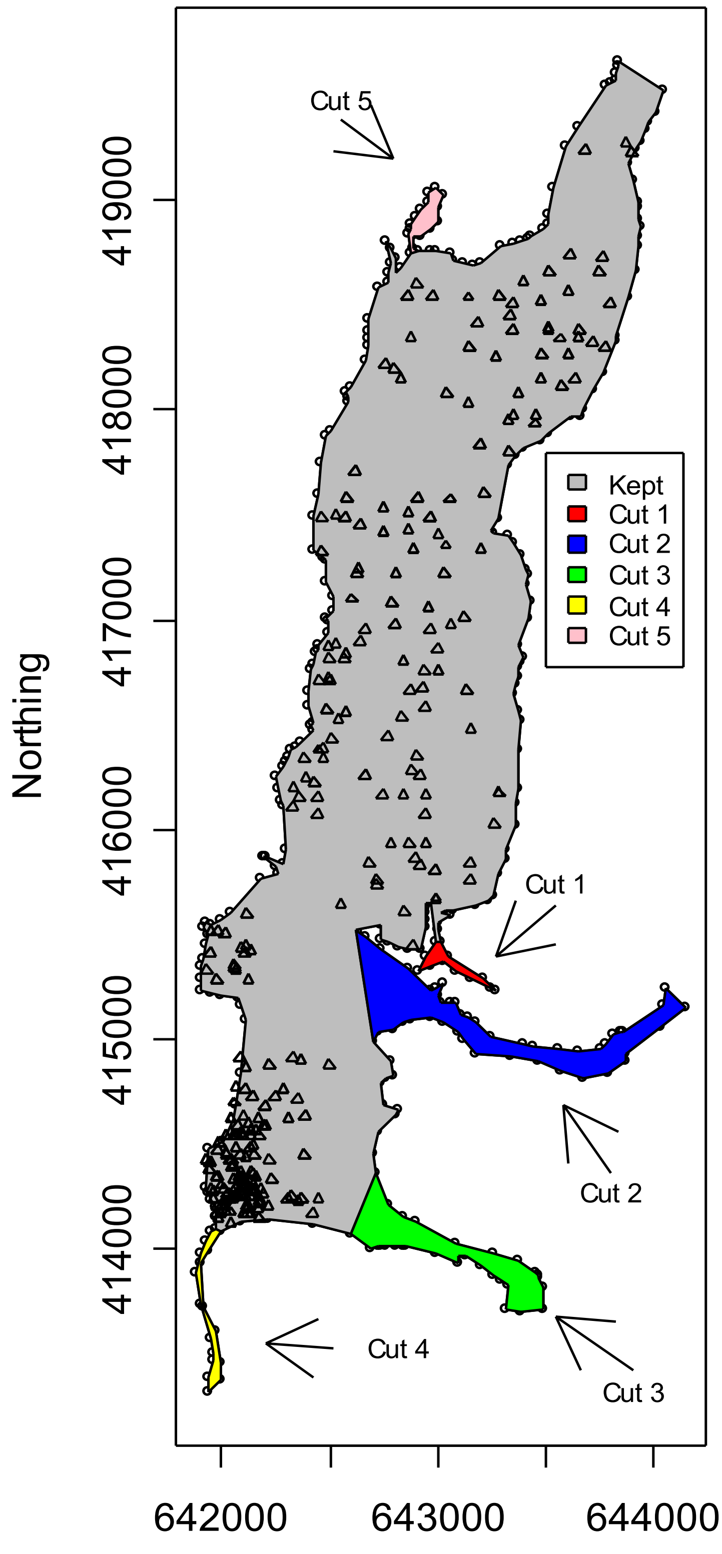


Table 6.2. Coordinates of chords cutting off parts of Little Lake Butte des Mortes.

		Northing	Easting
Cut 1	Vertex 1	415465.2	643012.5
	Vertex 2	415463.4	642991.4
Cut 2	Vertex 1	415522.3	642621.6
	Vertex 2	414986.3	642698.7
Cut 3	Vertex 1	414359.3	642714.9
	Vertex 2	414069.9	642595.8
Cut 4	Vertex 1	414083.0	641992.8
	Vertex 2	414101.6	641972.0
Cut 5	Vertex 1	418744.1	642873.8
	Vertex 2	418760.7	642912.5

Table 6.3. List of cases excluded due to missing values.

Dataset	Sample id	Missing
1989/90 Fox River Mass Balance Study	2A9.7	Depth
1989/90 Fox River Mass Balance Study	2C3.1 & 3C3.1	Depth
1989/90 Fox River Mass Balance Study	2E7.1	Spatial coordinates
1989/90 Fox River Mass Balance Study	2E7.2	Spatial coordinates
1989/90 Fox River Mass Balance Study	2E7.3	Spatial coordinates
1989/90 Fox River Mass Balance Study	2MC1	Spatial coordinates
1989/90 Fox River Mass Balance Study	2NS1.1 OF 2	Depth and spatial coordinates
1989/90 Fox River Mass Balance Study	2NS1.2 OF 2	Depth and spatial coordinates
1989/90 Fox River Mass Balance Study	2NS1.2of2	Depth and spatial coordinates
1989/90 Fox River Mass Balance Study	2NS2.2of2	Depth and spatial coordinates
1989/90 Fox River Mass Balance Study	2NS2.2 OF 2	Depth and spatial coordinates
1989/90 Fox River Mass Balance Study	2NS2.1 OF 2	Depth and spatial coordinates
1989/90 Fox River Mass Balance Study	2NS2.1of2	Depth and spatial coordinates
1989/90 Fox River Mass Balance Study	2NS3.2 OF 2	Depth and spatial coordinates
1989/90 Fox River Mass Balance Study	2NS3.1 OF 2	Depth and spatial coordinates
1989/90 Fox River Mass Balance Study	2NS3.1of2	Depth and spatial coordinates
1989/90 Fox River Mass Balance Study	3NS1.1	Spatial coordinates

1989/90 Fox River Mass Balance Study	3NS1.2	Spatial coordinates
1989/90 Fox River Mass Balance Study	3NS2.5	Spatial coordinates
1989/90 Fox River Mass Balance Study	3NS2.4	Spatial coordinates
1989/90 Fox River Mass Balance Study	3NS2.3	Spatial coordinates
1989/90 Fox River Mass Balance Study	3NS2.1	Spatial coordinates
1989/90 Fox River Mass Balance Study	3NS2.2	Spatial coordinates
1989/90 Fox River Mass Balance Study	3NS3.1	Spatial coordinates
1989/90 Fox River Mass Balance Study	3NS3.2	Spatial coordinates
1989/90 Fox River Mass Balance Study	3NS4.1	Spatial coordinates
1989/90 Fox River Mass Balance Study	3NS4.2	Spatial coordinates
1989/90 Fox River Mass Balance Study	3NS4.3	Spatial coordinates
1992/93 BBL Deposit A Sediment Data Collection	BA-SD34	Spatial coordinates
1992/93 BBL Deposit A Sediment Data Collection	BA-SD35	Spatial coordinates
1993 Triad Assessment	2C2 (Tr)	Depth and spatial coordinates
1993 Triad Assessment	2E8 (Tr)	Depth and spatial coordinates
1993 Triad Assessment	POG (Tr)	Depth and spatial coordinates
1994 GAS Sediment Collection	D-RI-Comp1(2-4)	Spatial coordinates
1994 GAS Sediment Collection	D-RI-Comp2(0-2)	Spatial coordinates
1994 GAS Sediment Collection	E-RI-Comp1(0-2)	Spatial coordinates
1994 GAS Sediment Collection	E-RI-Comp1(2-4)	Spatial coordinates
1994 GAS Sediment Collection	E-RI-Comp2(0-2)	Spatial coordinates
1994 GAS Sediment Collection	P-RI-Comp1(0-2)	Spatial coordinates

Table 6.4. List of locations north of the Little Lake Butte des Mortes excluded from the dataset.

Northing	easting	Depth stratum
419679.0742	644051.0881	1
419679.0742	644051.0881	2
419709.1066	643962.7776	1
419709.1066	643962.7776	2
419790.8251	644295.0179	1
419790.8251	644295.0179	3
419804.3195	643920.5937	1
419804.3195	643920.5937	2
419804.3195	643920.5937	3
419837.8256	644254.519	1
419855.014	643925.0916	1
419855.014	643925.0916	2
419966.5148	644210.0202	1
420120.2025	645313.4881	1
420120.2025	645313.4881	2
420156.0779	645230.8035	1
420671.1762	645963.1568	1
420671.1762	645963.1568	2

SECTION 7.0 – DEPTH AND CONCENTRICITY—RESULTS

In this section we carry out a kriging analysis and illustrate some of the issues in location of samples. The spirit of this section is to present a data kriging analysis as if it came from the phase I sampling of Little Lake Butte des Morts. The analysis is based on the cumulative data from Fox River sediment sampling programs. The analysis is, indeed, about the River, but the historic data are about to be replaced by more modern data, to be collected with more consistent and rigorous methods. Thus, this should be viewed as an "as if" example, but with an expected striking similarity to the new data about to be collected, based on the Fox River historic data.

7.1 Algorithm for Phase II sampling

Using the data set and depth stratum classes described above in Section 6, we examined the PCB concentrations using a kriging analysis for each depth stratum. This process involved fitting a variogram for each depth, generating an estimate of the mean and SE for a quite dense grid of "new" locations for each depth, and computing 95% confidence intervals for the concentration at each new grid point at each depth.

Figure 7.1 shows the variograms which were used for each depth. The solid curves are the theoretical models, while the dots are observed values. The parameters used in our exponential variogram models are given in Table 7.1. Using these variograms, we computed the kriging estimates for the mean and SE at each depth and at each point in our "new" location grid. The kriging estimates of the mean at each depth are shown in Figure 7.2. In Figure 7.3, we show the regions where the estimated PCB concentration is above 1000 ppb. It is clear that the uppermost depth stratum has the highest PCB concentrations; there are also large areas in strata 2 and 4 with high PCB concentrations. These results are summarized in table 7.2 in the column labeled "Figure 7.3". From the table,, approximately 63% of the area of the Lake has sediment at some depth that is over 1 ppm—the would be the minimal area to be remediated.

By examining Figures 7.2 and 7.3, it is clear that there is a high degree of concentricity across depth; that is, polluted regions at lower depths are generally located directly below polluted regions at shallower depths. The main deviation from this is the large polluted area in depth 4 (see Figure 7.2d), which has no companion area with elevated PCB concentration at depth 3. Figure 7.4 illustrates this by displaying an overlay of outlines of the regions identified in Figure 7.3. From this figure we see that although the 1+ ppm region in depth 4 is not concentric with depth 3, they are both mostly contained within the boundaries of the polluted area in depth 1. Figure 7.5 displays the union of the regions at all depths where the mean estimate exceeds 1000 ppb. This can be compared to Figure 7.3a to see that there is very little difference; thus, there is a high degree of concentricity.

Using confidence intervals, we determine which areas can benefit from further sampling in Phase II. In the regions where the upper confidence limit is below the 1 ppm (1000 ppb) threshold, we can conclude that remediation is probably not needed, because we are already 95% confident that the PCB concentration is below the threshold of 1 ppm. Regions where the lower confidence limit is above the threshold of 1 ppm will require remediation, because we are 95% confident that the PCB concentration is above the threshold of 1 ppm. For our example dataset, these areas are shown in Figure 7.6. This is a very small area (Table 7.2). Transition regions, where the confidence interval includes the threshold value of 1 ppm (Figure 7.7), are candidates for further sampling because we are not able to make a definite conclusion about the PCB concentration. Conservatively, these areas might require remediation because we are not able to reject the hypothesis that the PCB concentration is below the threshold. However, further sampling in Phase II can be directed to these areas to clarify whether remediation is needed and avoid unnecessary remediation. We refine our candidate areas for further sampling by considering only those areas in which the confidence interval contains the 1 ppm threshold and the mean estimate is below the 1 ppm threshold. Assuming that areas in the transition region will be remediated, it makes sense to avoid allocation of sampling resources to areas where the requirement for remediation is unlikely to change.

For our example dataset, we computed the 95% confidence intervals for the PCB levels in each depth stratum. Results relating to confidence intervals are shown in Figure 7.6-7.8, and Table 7.2 gives a summary of the areas involved in each of these figures. Because of the large amount of variation in the data, some of the confidence intervals are quite large. This leads to a large proportion of the lake area being in the transition region where the confidence interval includes the threshold value of 1 ppm, at least in the surface strata (0-10 cm.). In these areas, we are not able to confidently state that the area is clean or polluted. However, taking more samples would reduce the variance, thus making the confidence intervals tighter and more informative, eliminating some areas from the process of remediation. It is anticipated the phase I sampling grid of one/acre along with the cluster samples will considerably reduce the size of the transition area.

7.2 Phase II sampling approach

To maximize the usefulness of samples in Phase II, we will use Phase I data to determine locations where new samples would be most likely to reveal areas which do not need remediation. For a triangular sampling grid, this is done by considering each triangle in turn and applying several criteria. First, we only consider triangles in which the mean PCB estimate is below the threshold value of 1 ppm and the upper confidence bound is above 1 ppm. Figure 7.8 shows the areas which meet these criteria for our example dataset. Next, we assess the impact that the addition of another sample point in the triangle will have on the estimate of the SE. If the new point is placed in the center of the triangle, then the largest distance from any point in the triangle to the nearest sample point will be reduced from 133 feet to 67 feet (assuming that a 230 foot triangular grid is used in Phase I). We can use the variogram to estimate the reduction in SE which we would expect from this decrease in interpoint distance. By applying this adjustment to the confidence interval over the triangle, we can determine whether the upper confidence limit might be reduced enough to remove the need for remediation in this area. With this method, we can specify where to sample in Phase II.

Table 7.1 Variogram parameters by depth strata.

Depth	Range (meters)	Sill*	Nugget*
1	200	0.6	0.2
2	150	1.2	0.6
3	400	1.4	0.6
4	400	2.5	0.1
5	700	1.8	0.2

*These correspond to variance measures on the log scale.

Table 7.2. Summary table for areas

Relative Depth Stratum (cm)	Total Area	**Fig 7.3** **Minimum area likely to need remediation** Area over 1ppm expected concentration		**Fig 7.6** **Little or no additional sampling needed** Area with 95% lower confidence bound > 1ppm		**Fig 7.7** **Candidate areas for additional sampling** Area with 1ppm included in 95% C.I.		**Fig 7.8** **Highest priority for additional sampling** Area with upper 95% confidence bound >1ppm and expected concentration <1ppm	
	*acres**	*acres*	*% of total*	*acres*	*% of total*	*acres*	*% of total*	*acres*	*% of total*
0-10	457.8	284.8	62%	7.5	2%	449.1	98%	171.8	38%
10-30	457.8	33.0	7%	0.0	0%	452.2	99%	419.2	92%
30-50	457.8	0.0	0%	0.0	0%	402.5	88%	402.5	88%
50-100	457.8	36.7	8%	1.1	0%	269.2	59%	233.6	51%
100+	457.8	1.4	0%	0.0	0%	220.7	48%	219.3	48%
Union of Strata**	457.8	287.0	63%	8.6	2%	457.3	100%	457.3	100%

* Note: 1 acre = 10,000m^2
** "Union" indicates horizontal area which covers any location that includes at least one depth stratum satisfying criterion

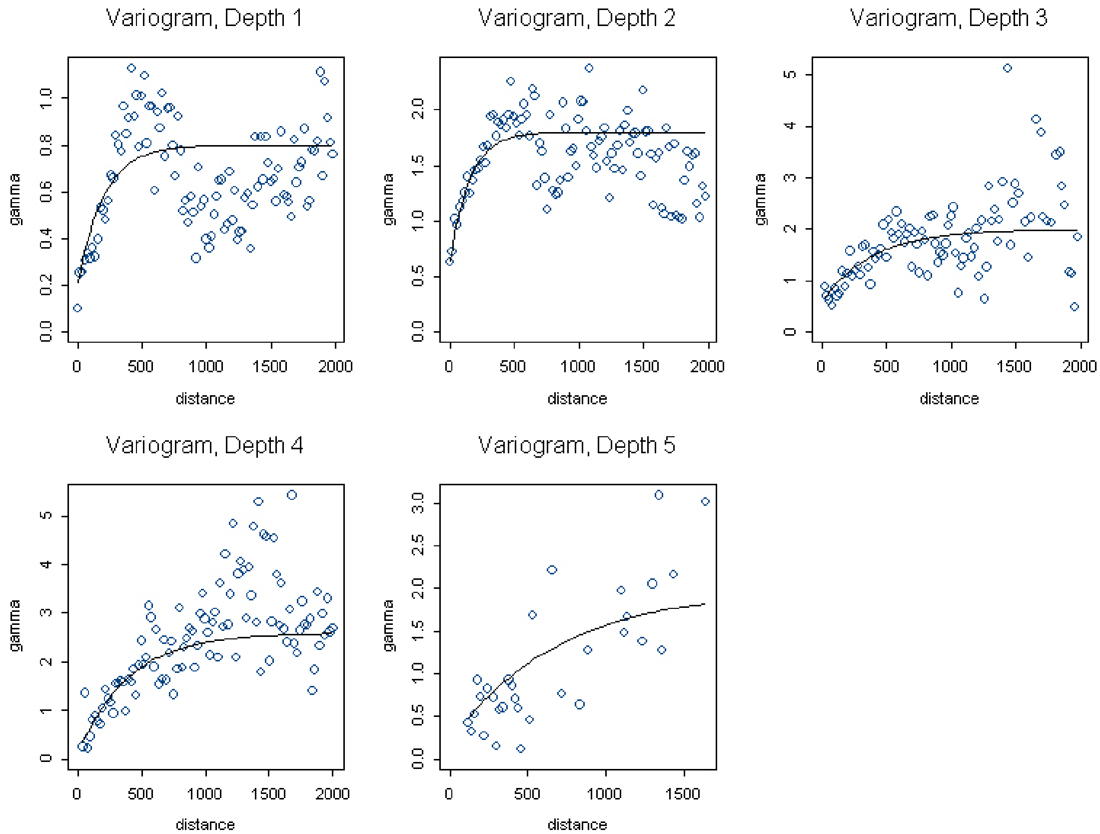


Figure 7.1 Variograms by depth stratum. For definitions of depth 1, depth 2, etc., see Table 6.1

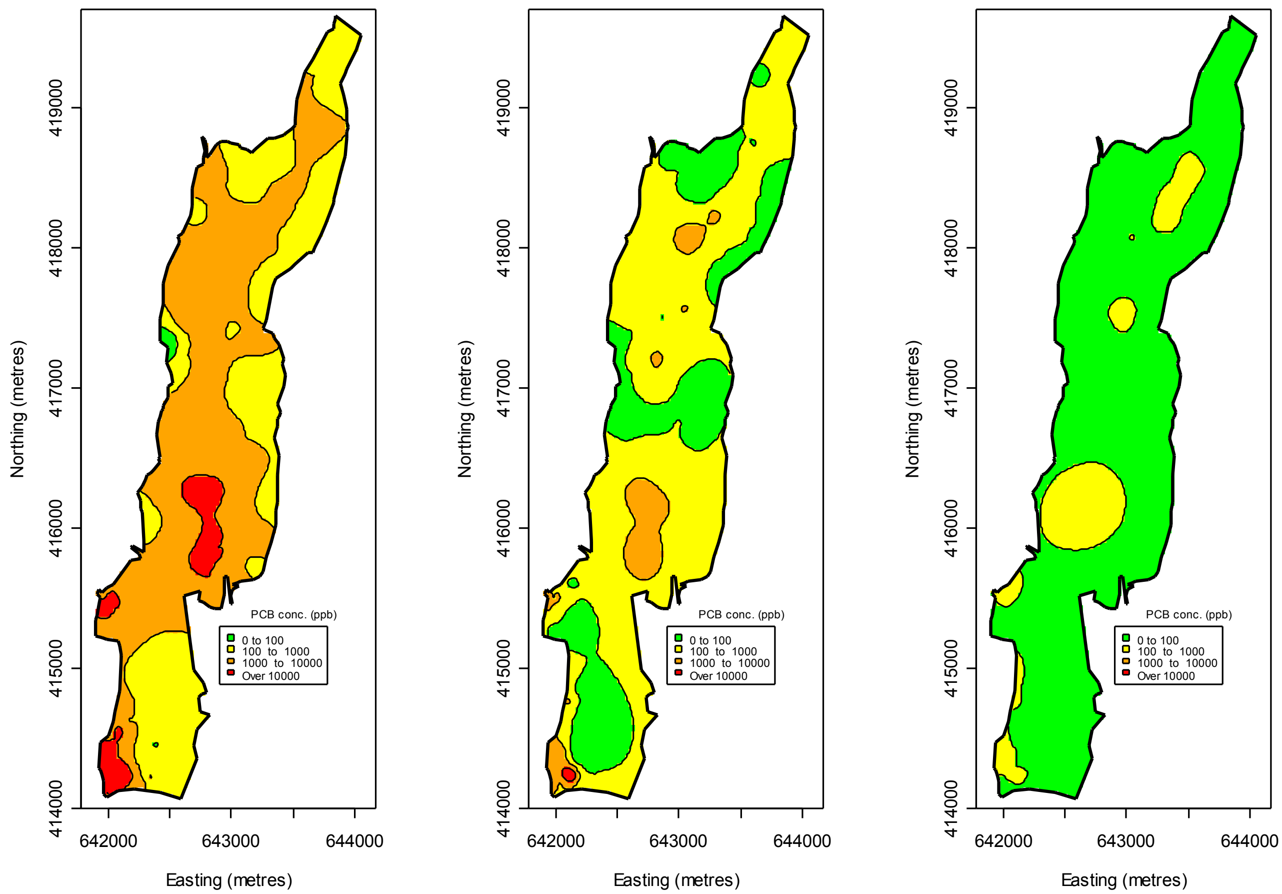


Figure 7.2a,b,c. Estimated PCB concentration for (left to right) 0-10cm, 10-30cm and 30-50cm, Little Lake Butte des Morts, Lower Fox River, Wisconsin

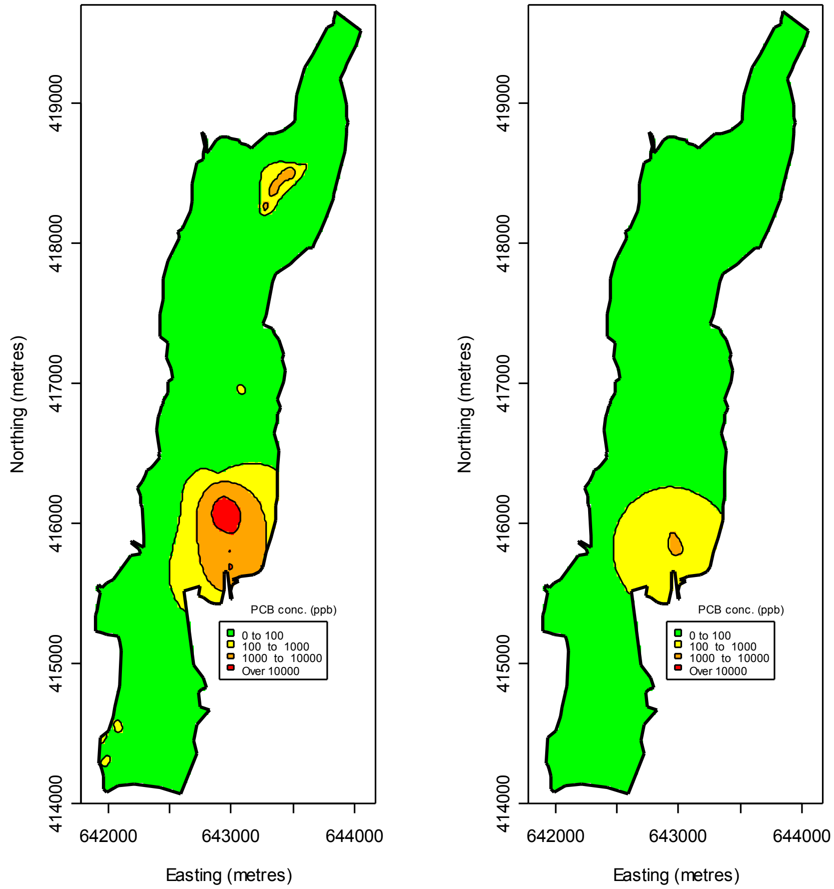


Figure 7.2d,e. Estimated PCB concentration for (left to right) 50-100cm and over 100cm, Little Lake Butte des Morts, Lower Fox River, Wisconsin

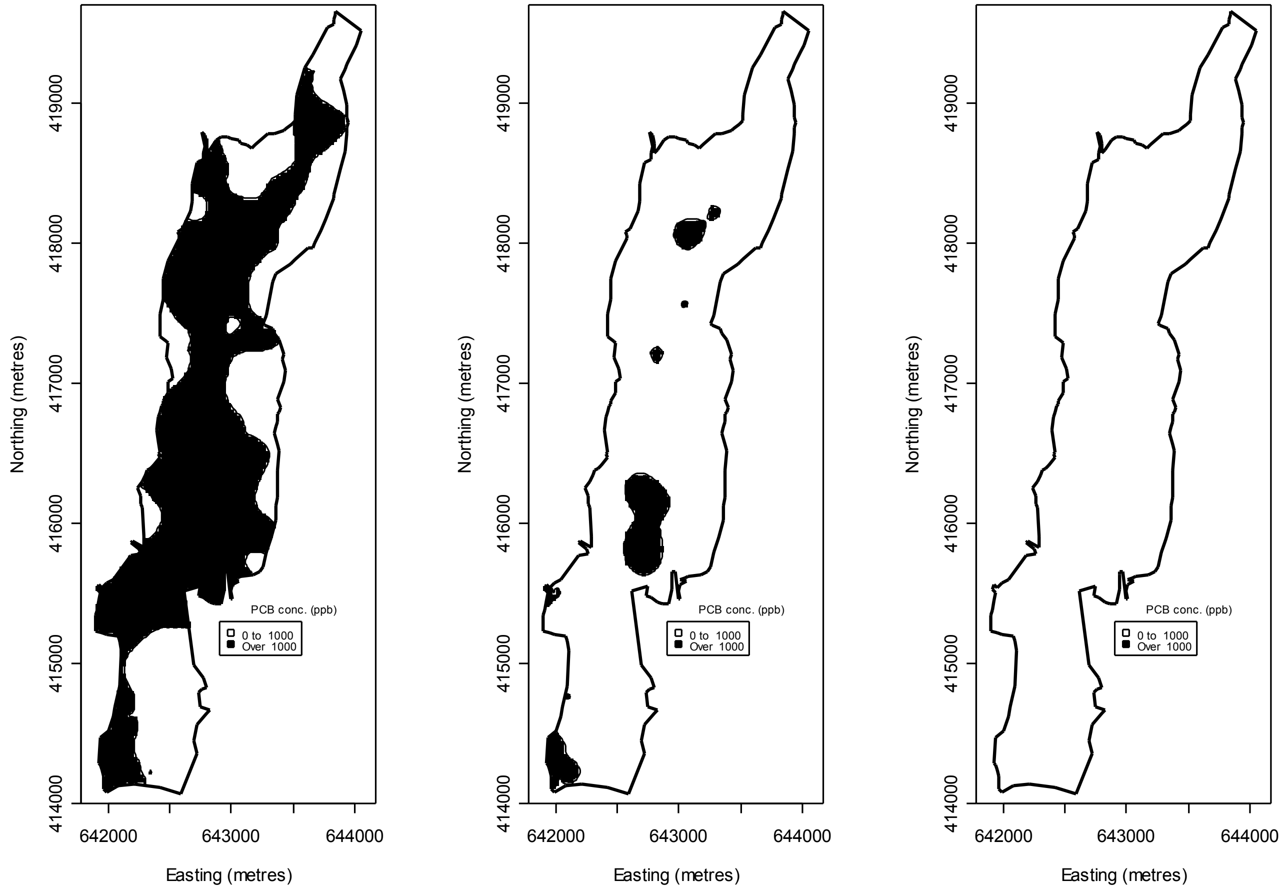
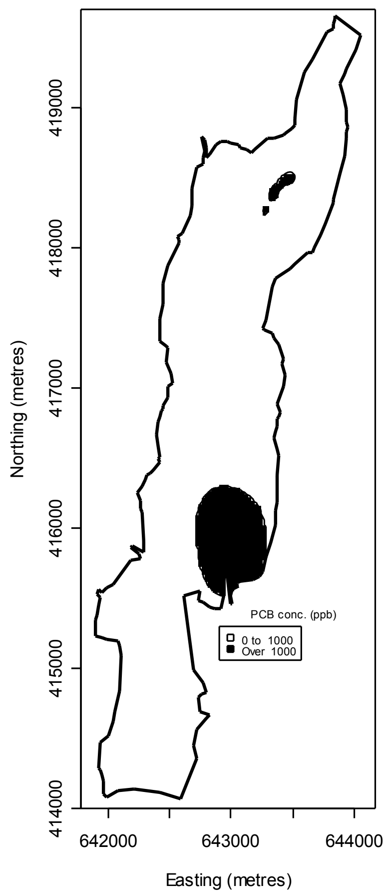


Figure 7.3a,b,c. Areas with estimated PCB concentration >1000ppb for (left to right) 0-10cm, 10-30cm and 30-50cm, Little Lake Butte des Morts, Lower Fox River, Wisconsin



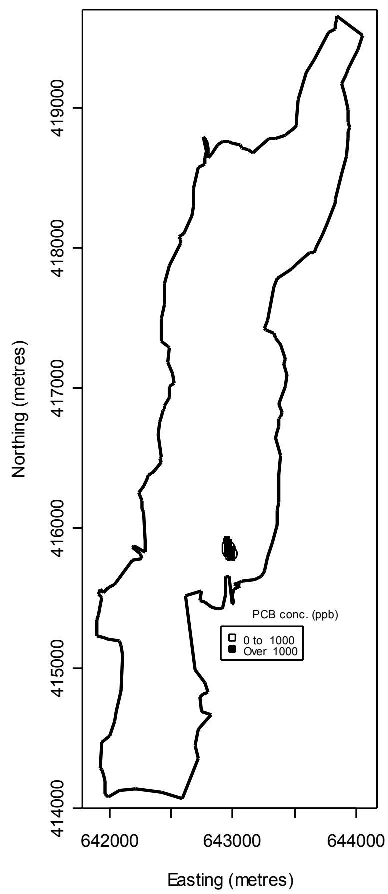


Figure 7.3d,e. Areas with estimated PCB concentration >1000ppb for (left to right) 50-100cm and over 100cm, Little Lake Butte des Morts, Lower Fox River, Wisconsin

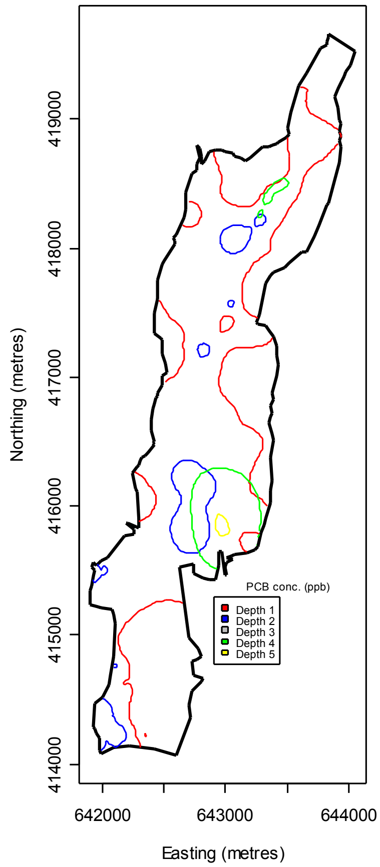


Figure 7.4. Areas with estimated PCB concentration >1000ppb for all five depth strata (overlay plot), Little Lake Butte des Morts, Lower Fox River, Wisconsin

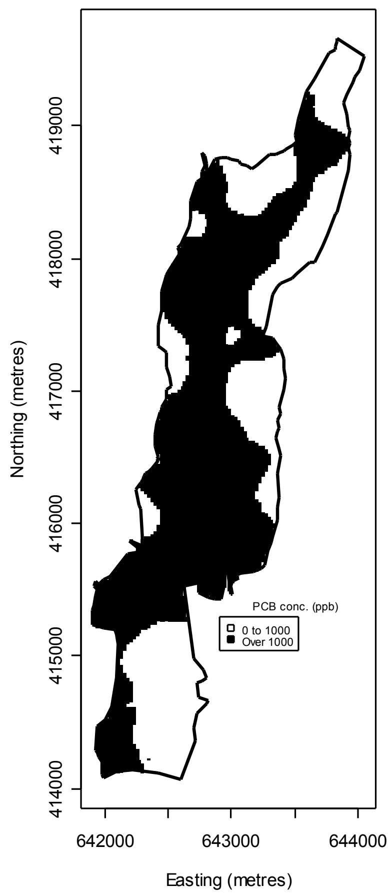


Figure 7.5. Area with estimated PCB concentration >1000pbb in at least one depth stratum, Little Lake Butte des Morts, Lower Fox River, Wisconsin

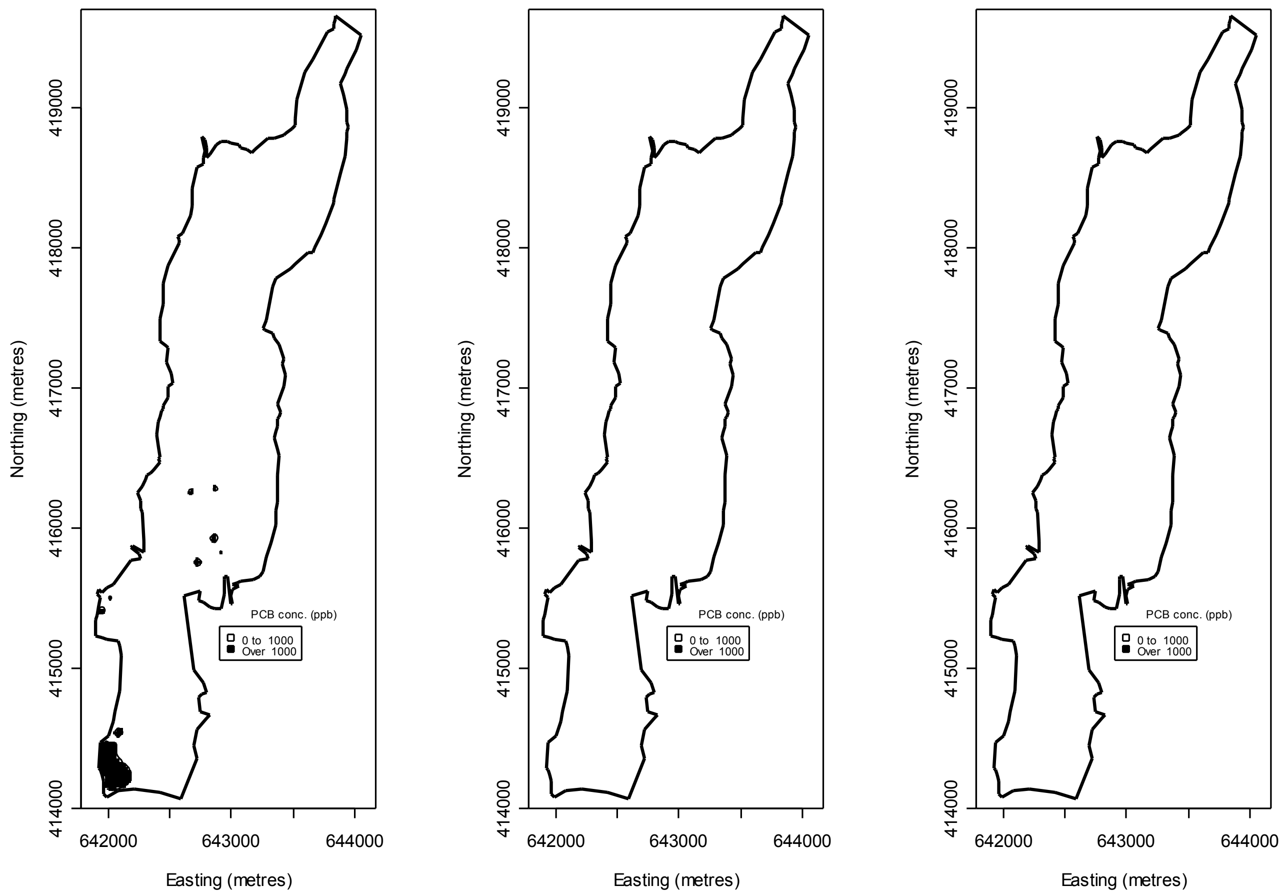


Figure 7.6a,b,c. Areas with little need for additional sampling: 95% lower confidence bound >1000ppb for (left to right) 0-10cm, 10-30cm and 30-50cm, Little Lake Butte des Morts, Lower Fox River, Wisconsin

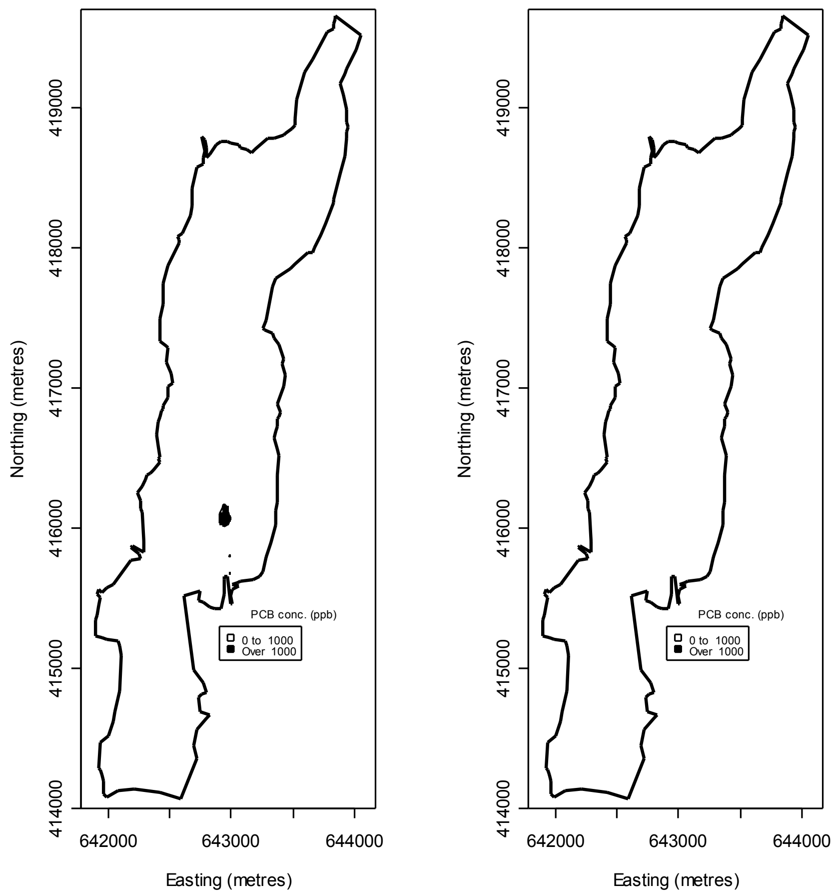


Figure 7.6d,e. Areas with little need for additional sampling: 95% lower confidence bound >1000ppb for (left to right) 50-100cm and over 100cm, Little Lake Butte des Morts, Lower Fox River, Wisconsin

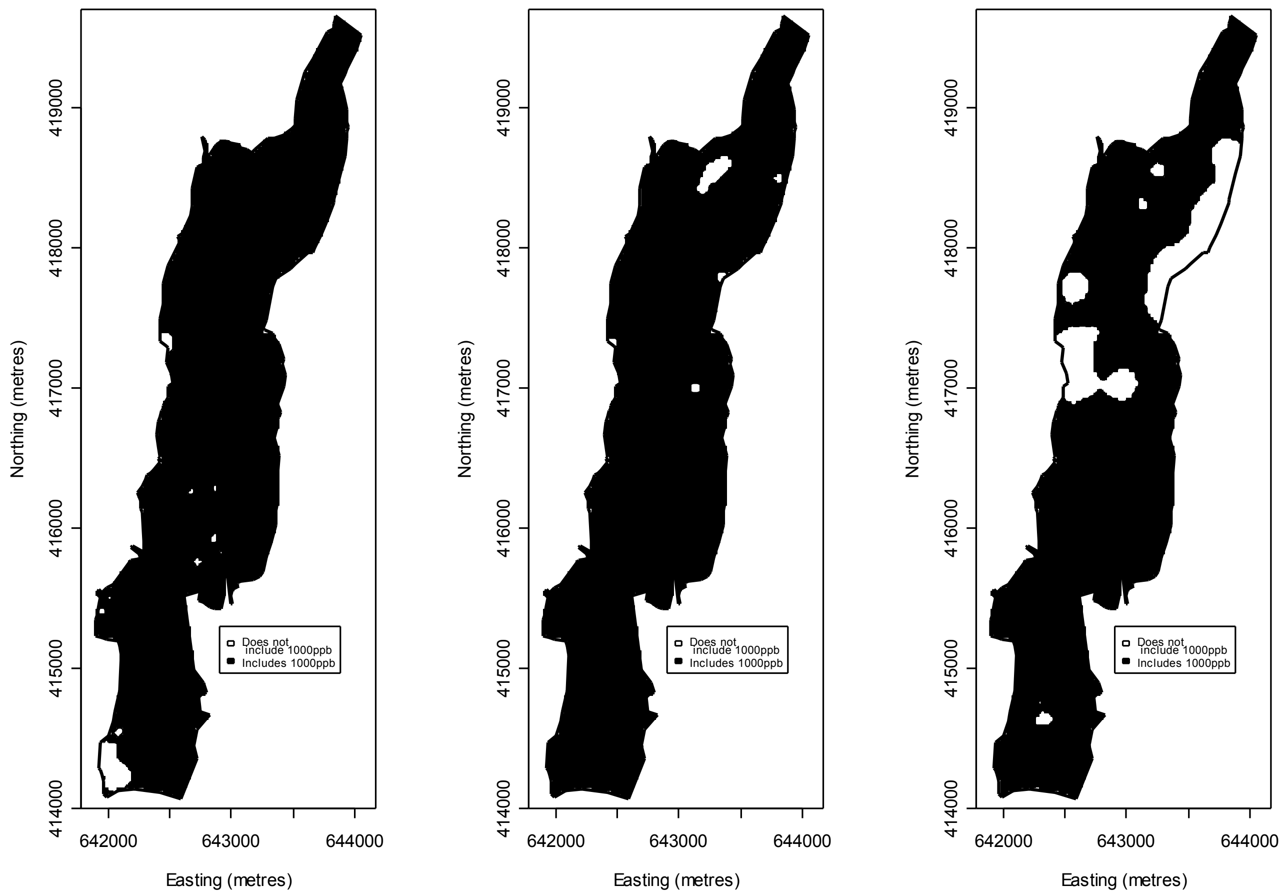


Figure 7.7a,b,c. Areas with need for additional sampling: 95% confidence bounds include 1000ppb for (left to right) 0-10cm, 10-30cm and 30-50cm,Little Lake Butte des Morts, Lower Fox River, Wisconsin

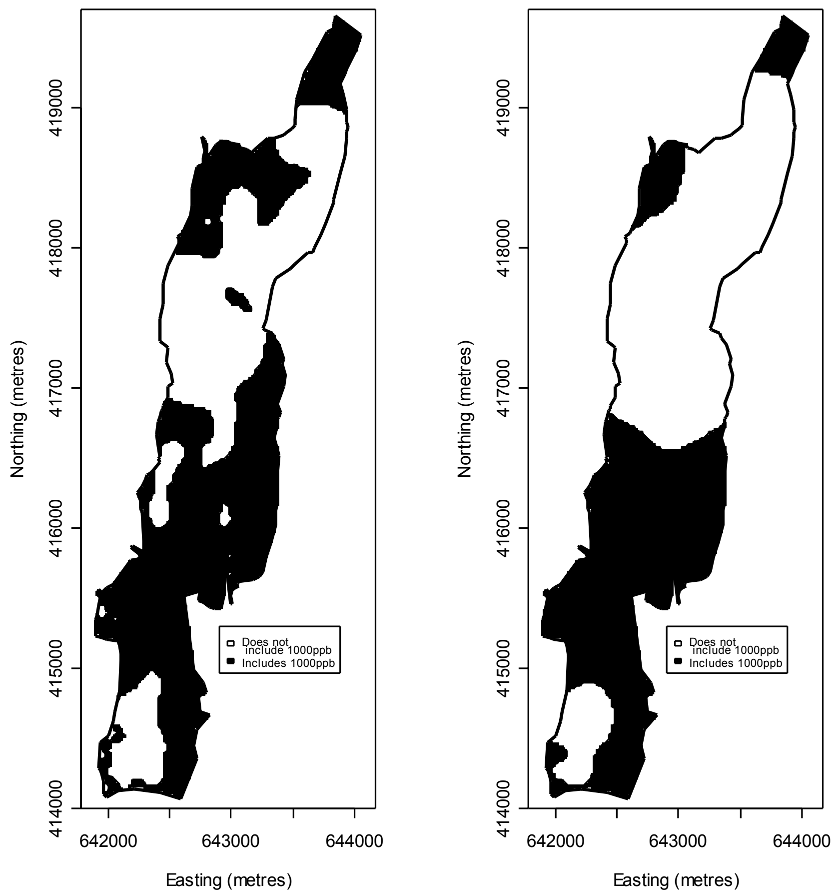


Figure 7.7d,e. Areas with need for additional sampling: 95% confidence bounds include 1000ppb for (left to right) 50-100cm and over 1000cm, Little Lake Butte des Morts, Lower Fox River, Wisconsin

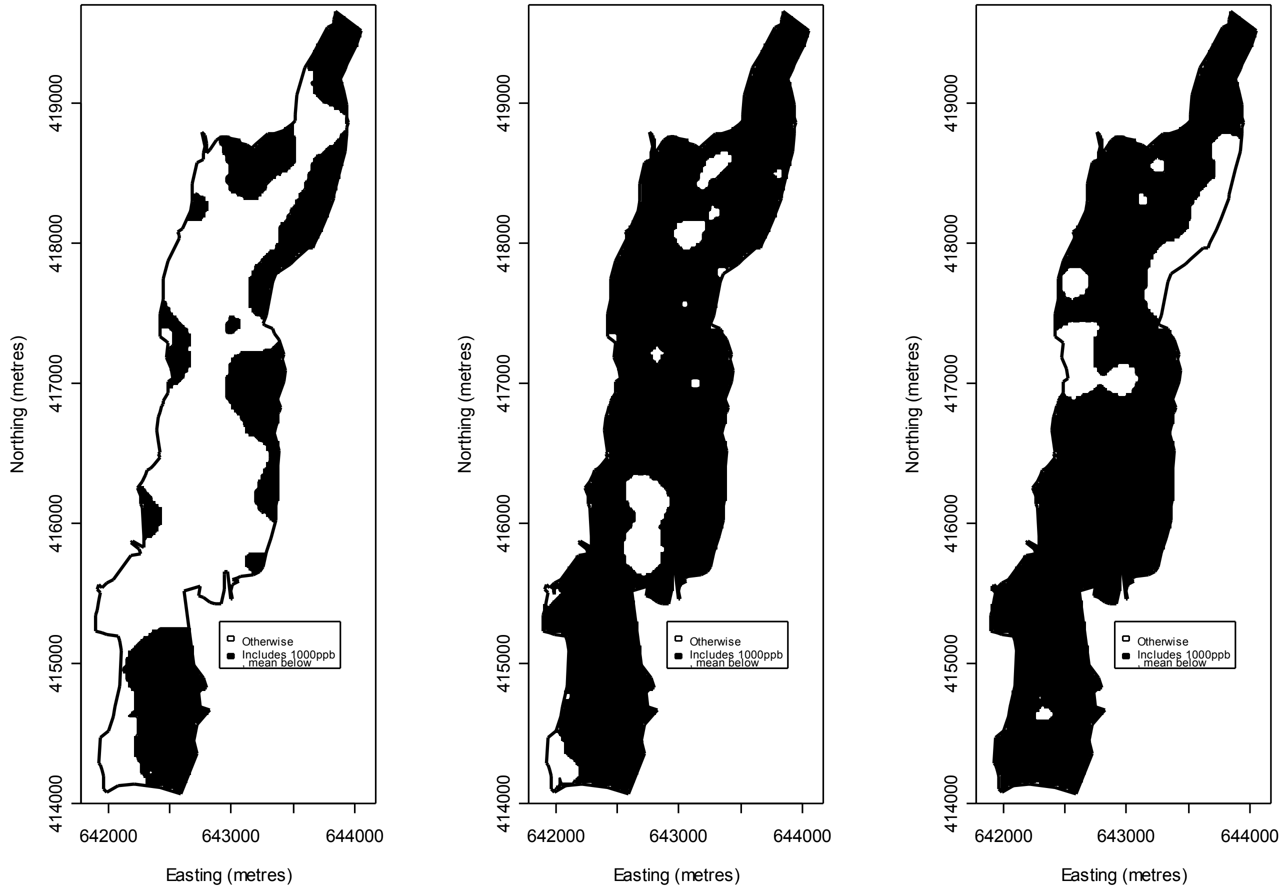
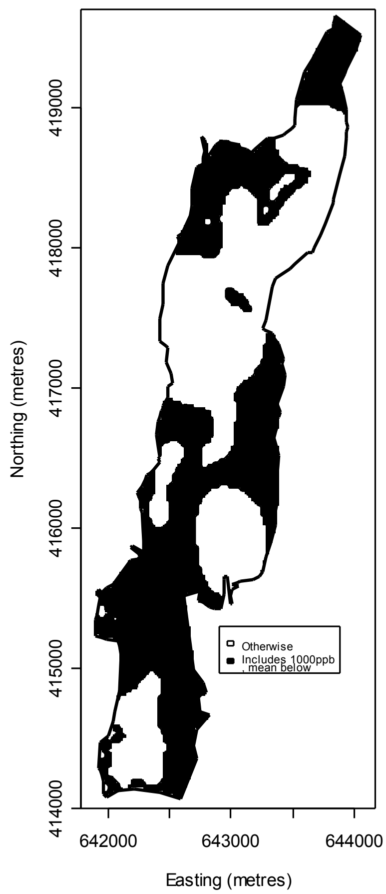


Figure 7.8a,b,c. Areas with highest priority for additional sampling: 95% upper confidence bounds > 1000ppb but expected concentration <1000ppb for (left to right) 0-10cm, 10-30cm and 30-50cm,Little Lake Butte des Morts, Lower Fox River, Wisconsin



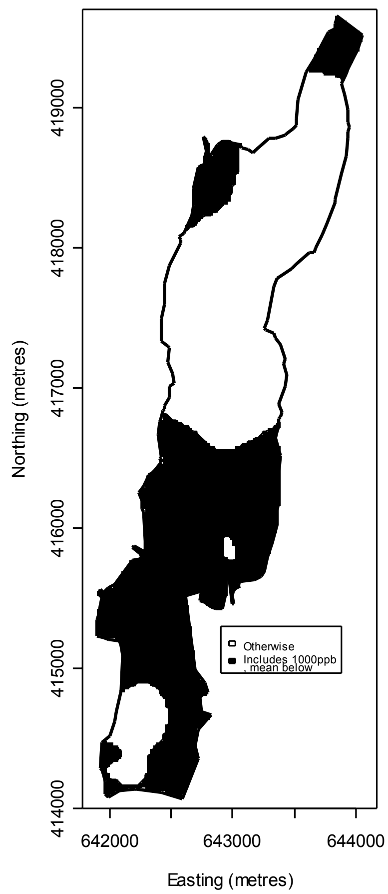


Figure 7.8d,e. Areas with highest priority for additional sampling: 95% upper confidence bounds > 1000ppb but expected concentration <1000ppb for (left to right) 50-100cm and over 100cm, Little Lake Butte des Morts, Lower Fox River, Wisconsin

SECTION 8.0 – ABSOLUTE AND RELATIVE DEPTH

8.1 Data will be collected and analyzed on the basis of relative depth (depth within the sediment below the sediment-water interface); nevertheless, there is a need to carry out the remediation on the basis of absolute depth (elevation). Between the alternatives of carrying out the data analyses on elevation and relative depth, the relative depth is a clear winner. Sediment tends to be laid down in layers that conform to the bottom of the river; rather than being laid down in elevation strata. Where the bank of the river plunging into the depths of the river is steep, the concentrations may change fairly gradually along the surface of the sediment as we fall into greater depth, but a horizontal layer that slices across multiple relative depths, could have very much more drastic changes in concentration, due to the fact that there would be intersecting layers that were deposited at different times. Analogously, a geologic layer in the earth is much more uniform if we follow it than a somewhat artificial layer formed by slicing at a fixed depth below sea level.

Then, the conversion from a relative depth to an absolute depth is necessary. This will be relatively straightforward and can be carried out by straight arithmetic interpolation. From the results of our kriging analysis, the concentration at any depth and horizontal location can be estimated along with its uncertainty. Thus, we can query the results of that analysis to find out the concentration at all points within the proposed 60-foot by 120-foot units of remediation. Thus, arithmetic interpolation will solve this problem. Due to the analyses of the data to be collected in relative depth strata (we understand that there will be 4-inch layers), there may be some discontinuities in the vertical concentration profile as we pass from one layer to another. However, due to the expected use of quite thin layers (four inches core segments within a single sampling location), the discontinuities should be minimal.

SECTION 9.0 – DISCUSSION

We have presented an approach which, in the first wave of sampling, sets us up for appropriate specification of second wave sampling, and, after second wave sampling, shows the method for estimating concentrations for any point at any depth. The procedures and estimates, however, are only as good as the methods and the data used. We consider some of the limitations in the next Section.

9.1 Limitations

After the estimation process is carried out and the area has been remediated, if the remediation volumes correspond to those designated by the response to the sampling results, we will be able to make a statement that if we go to a particular place and take a sample (with the core size used in the sampling effort) that we are 95 percent confident that the core sample will not include a concentration above 1 ppm. The content of this statement is very important: it does not state that we will not find any area above 1 ppm, but that only 5 percent of such samples are likely to fall above 1 ppm. There is a much stronger statement that could be made, but an enormous sampling and remediation effort would be needed to prove that statement true. The stronger statement is that we are 95 percent confident that <u>none</u> of a large series of samples taken within the area remediated or outside the area remediated would turn up a concentration of over 1 ppm. It would be statistically difficult to formulate the sampling and analysis plan and directions for remediation to support that statement, but it is clear that the effort would be enormous. The reason is that it is just impossible to prevent the occurrence of very small pockets of high PCB concentration that cannot be anticipated due to random variation across the field of sediment. Thus, the goal of the remediation effort should be to leave areas where concentrations above 1 ppm would be encountered only with a very low probability. Nevertheless, even after remediation, such isolated pockets of 1+ ppm PCB concentration are bound to occur.

A second consideration is that a statement of 95 percent confidence that samples will not be found above 1 ppm is very much tied to the size of the core samples taken. We understand that the samples are taken as 4-inch cores. (the discussion in this section is not tied to a 4-inch core. the size of the core, though fixed, is arbitrary for this discussion.) Inherent in the coring and analysis process is some unavoidable compositing. The 4-inch core is, presumably, thoroughly mixed for a given depth strata and, thus, represents soil in that stratum. If a narrower core was taken, it is likely that the core-to-core variability would be larger, up to the extreme (and ridiculous) case where the core would be so small that only a few grains of sediment would be taken in the core, the relative variability would be enormous, as one set of three or four grains might have no tracer of PCBs and another set might have a "few molecules" of PCBs attached to them and have a very high concentration.

On the other hand, if a thought experiment of cores one or two meters wide is contemplated, it is clear that the core-to-core variability would be much smaller, because much larger volumes of sediment are being mixed and, therefore, averaged. Thus, our statement that we are 95 percent confident that a sample taken outside of the area remediated will not have a concentration of 1 ppm <u>must include the core size</u> specification.

This rather strange condition, that our statements about an area and the PCB concentration remaining after remediation should be tied to the size of a tube used in data sample collection, is strange, but real. While it may seem absurd to the policymakers and those carrying out the activity in the field to even consider a core size that is so small it might only get a few grains of sediment in it and equally absurd to consider a core so large that it might include a one- or two-meter cross-section of sediment, these people should consider whether there is something also sacred about a 4-inch core.

In fact, we suggest that as part of the sampling process a core taken at a particular grid point, in fact, be several cores taken within one or two meters of each other (distances to be explicitly specified) in order to investigate the potential for compositing. This would be a “micro-cluster, not to be confused with the sample clusters described earlier. The more compositing that is carried out, the smaller the area that would need to be remediated. Given that a very large sum of money will be spent on dredging, it will be very worthwhile considering the size of the core that is obtained from sediment as a way to save substantial resources, funds and effort.

9.2 OU3 and OU4

Our data analyses covered Little Lake Butte des Mortes (OU1) but many of the methods will apply to OU3 and OU4. However, some new challenges are likely to occur there. Specifically, the nature of the River is different in OU3 and OU4 in that it is a flowing river rather than a combination of river and “lake”. Particularly, it is likely that there is considerable anisotropy (see section 9.3). Thus, some special methods will be needed to accommodate the different trends in concentration in the upriver/downriver direction versus the trends in the cross-river direction. Each new reach should be considered in itself and we should not assume blindly that the kriging parameters (which reflect the spatial distributions) and other assumptions carry over from one reach to another without any change.

As part of the anisotropy effect, the sampling grid may need to be quite different in OU3 and OU4. In particular, the triangular grid (equilateral triangles) for OU1 may need to be “squashed” in the cross-river direction. It is likely that the correlation between points drops off much more rapidly cross-river than up-river/down-river. This anisotropy can be addressed using the methods described in Section 9.3.

9.3 Anisotropy

Anisotropy is when the spatial correlation in the data differs in different directions. This may occur, for example, when the current in a river impacts deposition of pollutants. Deposits might be stretched out in the direction of flow, causing more spatial correlation in the direction of flow and less in a perpendicular direction. When anisotropy is present, a single variogram no longer accurately represents the spatial dependence in the data because the spatial dependence changes with direction.

Anisotropic variograms can be used to investigate anisotropy. An anisotropic variogram is computed for a particular direction, so a separate variogram could be created for each of several directions. Anisotropy may also be caused by underlying trends in the data; these can be identified and removed to resolve the anisotropy. Another approach to anisotropy is to perform a transformation of the coordinate system. This is particularly useful when the spatial dependence has simply been stretched in one direction (e.g., due to river flow); a coordinate transformation can appropriately "squash" that direction until the anisotropy disappears, and then the usual isotropic (directionless) variogram can be used on the transformed data.

9.4 Laboratory Error

Laboratory error is an important consideration in these analyses. We understand that laboratory error is such that a PCB concentration from a laboratory determination probably has an error +/- 85 %. Thus, an estimated concentration of 1 ppm could well be 1.85 ppm and could also be 0.15 ppm(+/- 85 % on the arithmetic scale). The laboratory error is folded into the general error of estimation and is a component of it. The larger the laboratory error, the less likely it is that areas between samples will have well determined concentrations. The larger the laboratory error; the larger the area that will need to be remediated.
We recommend that a thorough quality control program be used in this project which, fairly frequently, splits samples between two laboratories, and also splits samples within the same laboratory. Ideally, the laboratory will be blinded (having just a code attached to a sample) and will not be able to identify replicate samples.

9.5 Recommendations

We recommend that the following steps be taken in carrying out the sampling planning and future data analysis analysis.

- A preliminary analysis of historic data for OU3 and OU4 should be carried out to help determine the geometrical shape of the sampling lattice to be used in Phase I.
- We recommend that the policymakers and field staff consider compositing cores across a larger area than four inches (or the small core diameter that is currently used).

- We recommend that the analysis of sample results for Phase I and Phase II be carried out as "data analyses" rather than point-and-click kriging. In particular, there needs to be some consideration of anisotropy, model assumptions, and the possibility that different sections of the operating unit have different enough relative spatial distributions that the analysis and sample planning should be carried out separately for different parts of each operating unit rather than globally within the operating unit.

9.6 Conclusions

Sampling for remediation can be economically carried out in two waves and the first wave can supply the necessary information to guide the second wave of sampling. Sampling at one per acre is adequate for the first wave, accompanied by a number of small clusters of samples taken at short range around some of the nodes of the sampling lattice. The proposed new sampling, even at one per acre, will already considerably reduce the area whose estimated concentration or upper confidence bound may lie above 1 ppm, compared to estimates based on the historic data.

Second phase sampling should focus on areas where the new samples will both reduce uncertainty in estimation of PCB concentration and increase the area that can confidently be stated to be under 1 ppm concentration. The criterion and algorithm for selecting the second phase sample locations has been presented.

Deposits in OU1 tend to be "well-behaved" in the sense that areas needing sampling in deeper strata lie inside the horizontal boundaries of areas needing sampling in shallower strata. It is likely that the areas need remediating in deeper strata will lie inside the horizontal boundary of areas needing remediation in shallower strata.

Samples can be collected and data analyzed in the framework of relative depth (depth below the sediment-water interface) and then results can be translated to elevation (absolute depth) by simple interpolation.

The size of the area that will need to be remediated is tied both to laboratory error and to the physical diameter of the core that is used in sampling (or the area that is composited) at each sample node. Laboratory error and core (or compositing) size should be given due consideration.

The data analysis for sample planning and for estimation of PCB concentrations and confidence intervals is complex in methods and assumptions (due to the nature of the river and its deposits) and should be carried out as careful data analysis and not in an automated way.

Sampling Sediment in the Lower Fox River: How Many Samples?

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March 16, 2003

SUMMARY

This report makes the following points, based on good sampling practice and on analysis of data on PCB concentrations in sediment samples from the Lower Fox River, Wisconsin.

A two-stage sampling plan is recommended to make the best use of the sample budget. The first stage is used to determine where the boundary for remedial action is likely to lie and also to determine the spatial variability of PCB concentrations. The variability is important, because, for example, high variability will require a tighter sampling grid to pin down the remediation boundary than low variability. The second stage is used to more sharply define the remediation boundary. The two stage sampling avoids wasting intensive samples on sediment that is clearly within or clearly outside of the area to be remediated, e.g., areas firmly above, say, 10 ppm or below 0.1 ppm concentration.

Variability of PCB concentrations and uncertainty in concentration estimates must be factored in to the sample planning process. Remediating only the area with an <u>estimated</u> concentration above the action level (1 ppm PCB concentration) is going to leave behind unremediated areas that are above the action level but have not been detected. Deterministic methods that do not use standard errors for concentration, confidence intervals, probability, or some of the useful machinery of inference in the face of the unknown, are to be avoided. As an analogy, a well-intentioned program to provide services for the impoverished will miss many of impoverished clients if the program action area includes only census tracts with a median income below the poverty level. Tracts which have a mean income which is 10% above, 20% above, or even twice the poverty level are likely to have substantial numbers of individuals living in poverty, due to the substantial variability around the median. Variability around the mean is important in this example and in the Fox River.

Based on analysis only of surface sediments in areas that correspond roughly to deposits A and E of Little Lake Butte des Morts, a first stage of relatively sparse sampling (1 sample per acre, for example) and a second stage of additional sampling from a fraction of the same area (2-3 per acre for perhaps a third of the area) are likely to do the job. However, final sample numbers should be based on analysis of the multiple depth strata.

It would be wise to plan the sampling intensity and sample grid tailored to each deposit. E.g., a long narrow deposit is likely to need a different sampling grid and sampling intensity than a broad area. The different deposits can be expected to have different levels of variability, spatial distributions and correlations, so that "one size fits all" is not likely to work. Again, the first stage of a two-stage sampling program would provide an invaluable data to guide an economical and targeted use of a second wave of sampling.

This study has not yet addressed necessary modifications to the sampling plan—modifications needed to provide remediation boundary information simultaneously for multiple depth strata from the same sampling effort. It is recommended that some analyses of existing concentration data from different deposits and their multiple depth strata be carried out to further develop an economical sampling plan.

INTRODUCTION

This review describes a method for determining the sample size needed to specify which areas of the river should be remediated to confidently remove sediment above a threshold PCB concentration of 1 ppm. Due to the substantial spatial variability in PCB concentrations, even across small distances, it is difficult to accurately determine the boundary of the threshold concentration. Therefore, we suggest a two-stage sampling approach with low sampling intensity per acre at the first stage, perhaps one sample per 1–2 acres. The first stage also includes more intensive sampling in areas expected to contain the threshold concentration contour. The second stage would cover a limited sub-area of the deposit and would have a sample density based on results of the first stage. The second-stage sampling might cover about 30% of the deposit and have an intensity of 2–3 per acre.

This document also stresses the importance of addressing our uncertainty about the spatial distribution of PCB concentration. The uncertainty must be addressed in the sample planning process in order to be sure that the proper area is dredged (or capped). To determine the 1 ppm boundary exactly, an enormous number of samples would be required — theoretically, an infinite number. Therefore, with a finite sample, the 1 ppm boundary will be subject to some uncertainty, and that uncertainty must enter into the picture. Simply attempting to remediate the sediment within the estimated 1 ppm boundary will miss some areas over 1 ppm that lie outside the boundary. Thus, uncertainty is an inescapable aspect of sample planning, and a reasonable approach will incorporate the uncertainty into the planning process and attempt to control it.

VARIABILITY

Because spatial variability in PCB concentrations is important in determining sample size, we describe variability in this section. Indeed, spatial variability in PCB concentration is the main challenge in determining the location of the remediation boundary. If spatial variability is large (which means that samples taken relatively close together can have quite dissimilar concentrations), then a more dense sampling grid is needed to determine the location of the remediation boundary than if spatial variability is low. The substantial variability in the Lower Fox River can be illustrated by reference to Figure 1, which shows the concentration of selected samples in the surface sediments of the “Northern” deposit. This deposit overlaps deposit E (Little Lake Butte des Morts) in the traditional system of deposit designation. The samples selected for plotting in Figure 1 lie along the northwest and southeast edges of this deposit and have lower concentrations than the interior of the deposit.

Some examples from the figure show the large spatial variability of PCB concentrations. Note that at the bottom of the figure a concentration of 89 ppb occurs below and just to the right of a concentration of 1045 ppb. The separation of these two samples is 100–150 meters, yet the sample concentrations differ more than 10-fold. Just north of the 1045 ppb sample and to its right is a concentration of 2250 ppb, a doubling compared to its neighboring 1045 ppb sample. These examples show that concentrations in these surface deposits are indeed variable. One more example illustrates this large variability. In the upper left (northwest) of Figure 1, the third point from the top has a concentration of 1995 ppb, which is more than five times as large as a nearby sample (probably about 50 meters away) with a concentration of 430 ppb. Thus, several-fold differences in concentration can be observed among samples that are relatively close together. A perusal of other concentrations in this figure will turn up a number of other examples of dramatically different concentrations across relatively short distances.

The substantial variability is presented quantitatively as a plot in Figure 2, top two panels. These are variograms (a term to be defined shortly) for the "North" and "South" areas of Little Lake Butte des Morts. The "South" area overlaps deposit A in the traditional deposit designation system. The points in these plots show the spatial variance in PCB concentration observed between pairs of points separated by the distance shown on the X-axis. The Y-axis, "gamma," is the estimated variance on the natural log scale. For example, in the upper left panel ("North") of Figure 2, the point at the very top, which is somewhat distinct from the rest of the points, indicates a variance (gamma) of approximately 1.6 at a distance of approximately 330 meters. Thus for this deposit, pairs of samples separated by approximately 330 meters have a variance, on the average, of about 1.6 on the $\log_e$ scale. This one particular point in the plot is somewhat of an outlier, but other points also represent substantial variation. For example, even the smallest value (the lowest point in this panel of Figure 2) indicates a variance of about 0.4 at 100 meters separation between samples. This corresponds to a standard deviation on the log scale of about 0.6 (= $\sqrt{0.4}$), which, on the original scale, indicates that it would be very common to have twofold ratios [$2 \approx \exp(0.6)$] and not uncommon to have four-fold ratios in concentrations between samples separated by 100 meters [$4 \approx \exp(1.96 \times 0.6)$, where "1.96" is used to provide a 95% confidence interval for ratios].

Each of the points in this panel of Figure 2 represents a distance bin. The variogram is formed by taking all pairs of samples from a data set, finding the variance of each pair, and finding the distance between the pair. Then, bins of the distances are created and the variances are averaged for all pairs in each distance bin. For the North area, the number of pairs in each bin ranges from 9 to 93; and most bins have more than 40 pairs (Figure 2). However, the two short-range bins centered at 77 and 100 meters, have only 9 and 16 pairs, respectively, which is less than the 30 minimum recommended for reliable variance estimation. For the South area, there are 15 to 207 pairs per bin, with most above 70 pairs. The bin centered at 9 meters is the only bin with less than 30 pairs (15 pairs in this bin).

There are 18 distance bins in the North variogram plot, but note the lack of observations below about 80 meters. Even though deposit E was fairly heavily sampled, there is still a shortage of closely spaced pairs of samples. The smooth line through the set of points in Figure 2 is an estimated variogram function, showing how the variance between pairs of samples varies with the distance between the pair. The fitted equation for the smooth line depends on three important quantities: (a) the range, which is the distance beyond which pairs of points appear to be statistically independent (387 meters in this plot, where the smooth line levels off); (b) the sill, which is the value of the variance at the range and beyond (sill = 1.3 in the Northern variogram in plot); and (c) the "nugget" variance. The term "nugget" comes historically from the mining industry, where it describes the variability caused when one sample happens to strike a nugget of ore; here, the nugget variance denotes the variability between samples taken close together. The nugget effect in the North variogram is approximately 0.28, which means that samples that are taken even quite close together are apt to have a variance of 0.28 on the log scale or a standard deviation of approximately 0.5. Thus, it would be very common to find two-fold differences in concentration among samples at short range, and three-fold differences would not be uncommon.

The nugget effect is somewhat uncertain, due to the lack of samples taken close together. In the South variogram (around deposit A), the range is 362 meters, very similar to the range in the North area. The sill, though, (gamma = 3.4) and the nugget variance (= 1.09) is considerably higher than in the North area. The nugget effect in the South area is substantial, indicating that at very close range it would be common to find nearly three-fold ratios of concentration, and, as well, not uncommon to find eight-fold ratios.

The variograms in Figure 2 are based on historical data, which grew out of the interests of various sampling and investigation teams. The locations of the samples are shown in the bottom of Figure 2. The lack of samples taken close together is apparent from the lower left panel. Also, in the locations for the South data (lower right panel), there are three or four clusters of points close together, and these clusters would dominate the nugget effect. In future sampling, pairs of proximate samples should be sprinkled strategically around the area of interest.

In summary, there appears to be a large short-range and an even larger long-range variability in sample concentrations. The historical data, though far more informative than no data at all, lack information on the nugget effect, which is so important in sample planning.

SPATIAL DISTRIBUTION OF CONCENTRATIONS

This section paints a picture of the spatial distribution of PCB concentrations and spatial distribution of variability in the North and South deposits. The PCB concentrations vary substantially over the spatial extent of the two deposits considered here. Figure 3 is the result of a kriging analysis of the North and South deposits (Cressie 1993). The upper paired panels show the estimated concentration vs. north and east coordinates, the middle strips are the key for the concentrations, and the bottom panels outline the area estimated by the kriging method to have over a 1 ppm concentration.

Figure 4 shows the standard error of the estimated concentrations from the kriging method. The top two panels show the standard error (SE) of PCB estimates for the deposit, the middle strips are the key to the SEs, and the bottom two panels repeat the sampling locations from an earlier figure. One very striking aspect of these plots is that the standard errors are lower (darker spots in the upper two panels) around the sampling locations — a phenomenon that is to be expected: as we move away from sample locations, the uncertainty about the concentration becomes larger. The North deposit has a more even distribution of sample locations and generally lower PCB concentrations than the South area; the standard errors in the North area are generally lower than in the South area. The South deposit tends to have more clustered observations and higher PCB concentrations and standard errors.

IMPACT OF VARIABILITY AND SAMPLE DENSITY ON MAGNITUDE OF AREA TO BE REMEDIATED

The impact of variability and especially the nugget effect on sample size planning can be illustrated by an example in (Table 1) for the Northern region. In this example the nugget effect dominates the sample planning effort, and if taken literally, would require a very large number of samples. Table 1 presents hypothetical sampling scenarios, indicated in the left column as samples of from one up to eight samples per acre. The separation between samples on a square sampling grid would be 63.6 meters down to 22.5 meters. (*A square sampling grid has been used for computational simplicity. In reality, a triangular or hexagonal sampling grid may be preferable*.) Based on the variability from the variogram and the kriging analysis presented earlier, the standard error of the estimated concentration at the center of the square sampling grid can be estimated. The standard error (on the log scale) of an estimated concentration at the center of the grid (an unsampled point) is given in the column "Maximum Predicted SE." At a sample density of one per acre, the estimated standard error at the center of the grid would be 0.7, which means that the upper bound of a one-sided 95% confidence interval for the concentration at the middle of the grid would be three times as large as the observed concentration itself. Therefore, an area would have to be dredged down to a boundary of 316 ppb (from he table) to provide 95% confidence that samples taken outside this boundary would have less than 1 ppm concentration. Because concentrations taper off gradually over space, the area above 316 ppb is enormous. The area that would need to be dredged if sampling occurred at one per acre is over 2,000,000 m^2 (almost 500 acres)! The column "Ratio to Mean" of Table 1 indicates the area that would need to be remediated divided by the area with a mean estimate over 1 ppm. Thus, two and a half times the area estimated to be over 1 ppm would have to be dredged to have 95% confidence that samples taken in other areas would be under 1 ppm. There is not much decrease in size of this dredged area with greater sampling intensity. As can be noted in the table, if sampling intensity is as high as eight per acre, the area to be dredged is still well over twice the area estimated to be within the 1 ppm contour. The reason for the large additional area to be dredged is the nugget effect, which is provided in the last row. (*Technical Note: The area to be dredged noted in Table 1 probably includes some area on dry land. In this analysis we did not apply a river-shaped "cookie cutter" and eliminate areas lying outside the river boundary*.)

Given that the nugget effect is very important, it is essential to determine it accurately. To do so, some samples must be taken close together.

We recommend a two-stage sampling approach. The first stage of sampling provides to provide enough samples to get the "lay of the land" regarding PCB concentrations, and to have some samples spaced close together to determine the nugget effect. The first stage of sampling could be fairly sparse. From the data observed for surface sediment in deposits A and E, a sampling intensity of one per acre or one per two acres would probably be adequate. However, superimposed on this first wave of somewhat sparse sampling would be a smaller number of samples taken close together. There needs to be a sufficient number of closely-spaced samples to estimate the nugget effect. In general, the variogram method works best with at least 30 samples per distance bin. Thus, in the North area of about 400 acres, if samples were taken with an intensity of 0.5-1 per acre, approximately 200-400 samples would be needed. If, superimposed on this, an additional 40-80 samples were taken at close range, particularly in areas expected to have a concentration in the neighborhood of 1 ppm, the results would be very useful both for determining the broad pattern of concentrations and the nugget effect. In the second stage of sampling, based on the estimated spatial distribution of PCBs from the first sampling wave, additional samples would be taken near the estimated contour of 1 ppm, both to further define this boundary and to refine the estimate of the nugget effect in areas close to the 1 ppm threshold.

OTHER SAMPLING CONSIDERATIONS

The Northern and Southern areas are probably somewhat isotropic in spatial correlation, meaning that the correlation between pairs of samples does not depend particularly on the orientation — that is samples taken 15 meters apart would have about the same variance regardless of whether the axis between them runs north-south or east-west. This isotropic correlation is probably not true of other reaches of the river. In particular, the last reach — De Pere to Green Bay — is probably highly anisotropic. That is, the deposits tend to be long and narrow, and concentrations probably change much more rapidly across the river than up- and down-river. The sampling grid would need to be compressed perpendicular to the river.

Compositing of closely spaced samples may be helpful in eliminating variability that happens on a very small scale and is not considered important. The taking of a sediment core already implies composting the small area within the cross-section of the core. No one would affirm that variability within that tiny area is important. Similarly, the variations in concentration within a meter or even 10 meters diameter may be considered unimportant, as long as the mean PCB concentration of the area is low. The decision on the size of the area to be represented by a composite sample could be based on typical feeding area of fish and other wildlife, or other considerations of natural exposure averaging (a type of natural "compositing") as it occurs through behavior of animals or humans.

DISCUSSION

There are two opposing forces in sample planning. Having samples evenly spread out in a grid covering the region minimizes the subset of areas that are "neglected" by not having samples in their vicinity. On the other hand, having samples close together allows us to get a more accurate estimate of the important nugget effect. It is very difficult to address these two needs in one sampling episode. Thus, it will be helpful if two waves of sampling are taken. In one wave, our goal is to broadly estimate <u>concentrations</u> by spatial location, and to get the general lay of the land. In the second wave, our goal is to define the remediation boundary more explicitly and more precisely estimate the nugget effect in the 1 ppm region. The empirical part of this investigation has focused on surface deposits only. A sampling plan that is ideal for the surface deposits may not work for subsurface sediment. Without some preliminary analysis, it is difficult to determine the sampling intensity that best accommodates the various depth strata of sediment. However, it is likely that two-stage sampling will work well for all depth strata.

An entirely different approach to sample designation is possible, but leads to rather large sample sizes. This approach finds the sampling intensity that would be needed to detect "hot spots" of various sizes. Table 2 illustrates the results of such an analysis. Here the simplified model is that a hot spot is circular, defined by its diameter, and the sampling grid is rectangular. In this simple model the nodes of the sampling grid can be thought of as pegs on a smooth surface and the hot spot can be thought of as a circular hoop that is thrown down. A hot spot is "detected" if the hoop encircles at least one peg. The table shows the diameter of a hot spot that has 95% chance of detection (only 5% chance of passing undetected) with the sampling intensity as noted. Thus, for example, with one sample per acre, a hot spot of 38 meters diameter or larger has 95% chance of detection. Very large sampling intensities are needed to ensure that only very small hot spots are missed.

RECOMMENDATIONS

1. The historical data for all deposits and depth strata should be analyzed to determine the nugget effect and the capacity of one sampling scheme to serve the sampling needs for all depth strata.
2. Two-stage sampling is recommended, as it will focus sampling effort on the areas that matter, save sampling cost, and better define the area to be remediated.

3. Spatial variability of PCB concentrations is a key component of sample planning and should be modeled and incorporated in the analysis. Specifically, estimates of concentration are not very meaningful if their precision (SE) is not known.
4. If the inverse direct weighting (IDW) method is to be used in mapping of concentrations, a method should be developed to derive the SE of concentration estimates from this method.. Kriging directly supplies the SE of estimates and may be preferable to IDW. The performance of the two methods can be compared on existing data sets.

REFERENCE

Cressie NAC. *Statistics for Spatial Data*, revised edition. New York: Wiley, 1993.

Table 1: Sample density and dredging area for the Northern region.

Northern region					
Distance between samples	Sample density	Maximum predicted SE	Max PCB conc. allowed* (ppb)	Area above max (sq. meters)	Area: Ratio to mean
63.6 meters	1/acre	0.70	316	2003257	2.57
31.8 meters	4/acre	0.64	348	1946286	2.49
22.5 meters	8/acre	0.62	360	1921516	2.46
limit - "nugget" effect		0.53			
Area exceeding 1000 ppb for mean estimate: 780867.6					

*Remediate area above this concentration

Table 2: Size of hotspot which can be detected at various sample densities.

Samples per acre	Diameter (meters) of circular hotspot that has at least 95% chance of detection
0.5	153
1	76
2	38
3	25
4	19
6	13
8	10

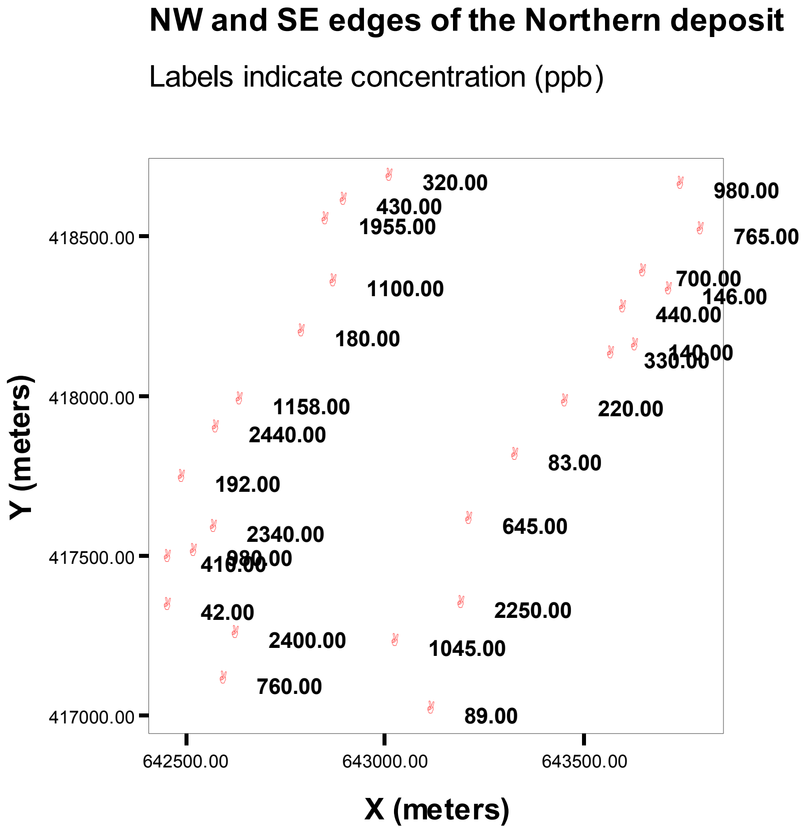

Figure 1: Sample concentrations. The PCB concentration (ppb) is shown for samples around the edges of the North region, with distance in meters to the east on the X axis and to the north on the Y axis.

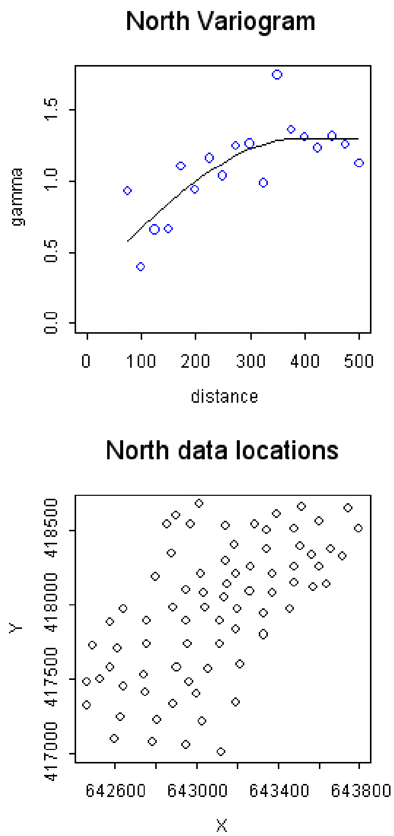

Figure 2: Variograms. The upper left panel displays the observed (dots) and estimated (solid line) variogram function for the North region, and the upper right panel shows the observed (dots) and estimated (solid line) variogram function for the South region. The lower panels show the locations of samples in each region, with distance in meters to the east on the X axis and to the north on the Y axis.

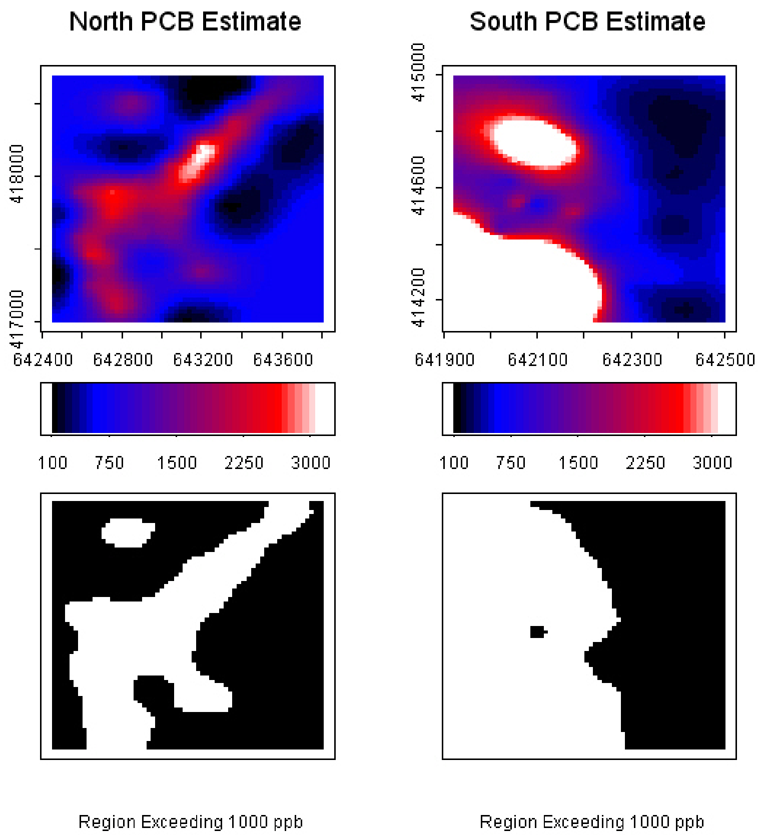

Figure 3: Estimates of PCB concentration. The upper panels show the kriging estimates of PCB concentration in the North and South regions, with the color key given by the strip in the middle. The lower panels display the area estimated to be above (in white) and below (in black) a threshold of 1 ppm.

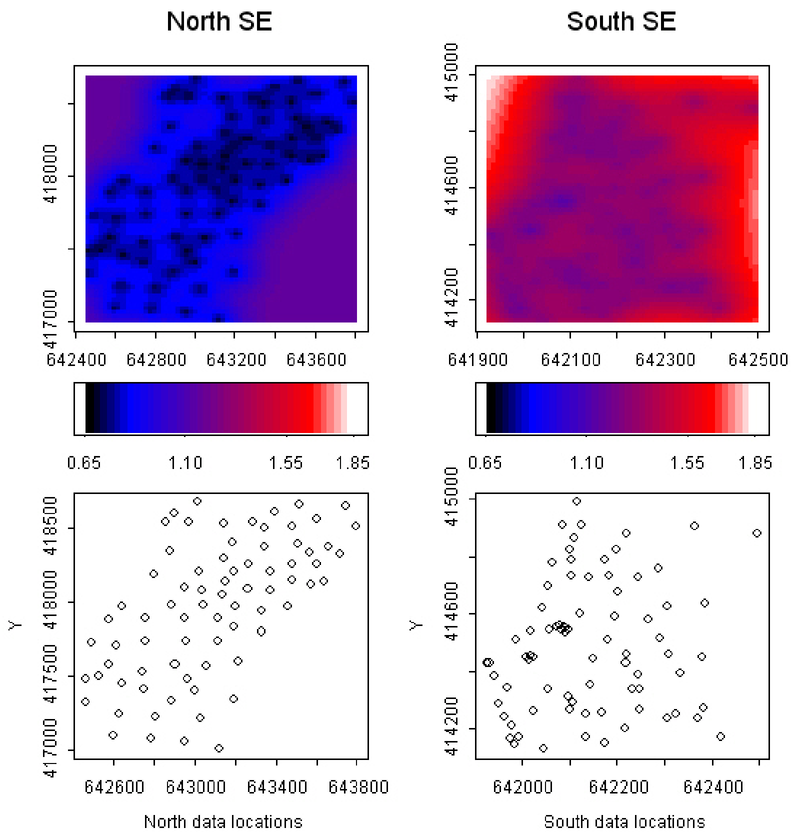

Figure 4: Standard errors of the PCB estimates. The upper panels show the standard errors associated with the estimates of PCB concentrations for the North and South regions; the strip in the middle gives the color key. The lower panels show the locations of samples in each region, with distance in meters to the east on the X axis and to the north on the Y axis.